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US Army Corps
of Engineers
Hydrologic Engineering Center

GENERALIZED COMPUTER PROGRAM

D2M2

Dredged-Material Disposal Managment Model

User's Manual

July 1984

CPD-47

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SUMMARY

The Dredged-Material Disposal Management Model, D2M2, is a simulation-optimization model designed to provide information required to answer the following disposal management questions:

1. If a specified long-term operation policy is followed for an existing or proposed dredged-material disposal system, what is the final status of the system, given the initial conditions, system physical and economic characteristics, and dredged-material volume estimates? What is the cost of following the operation policy? Must additional disposal-site capacity be provided?

2. What is the least-costly long-term operation policy for an existing or proposed disposal system, given initial conditions, system physical and economic characteristics, and dredged-material volume estimates?

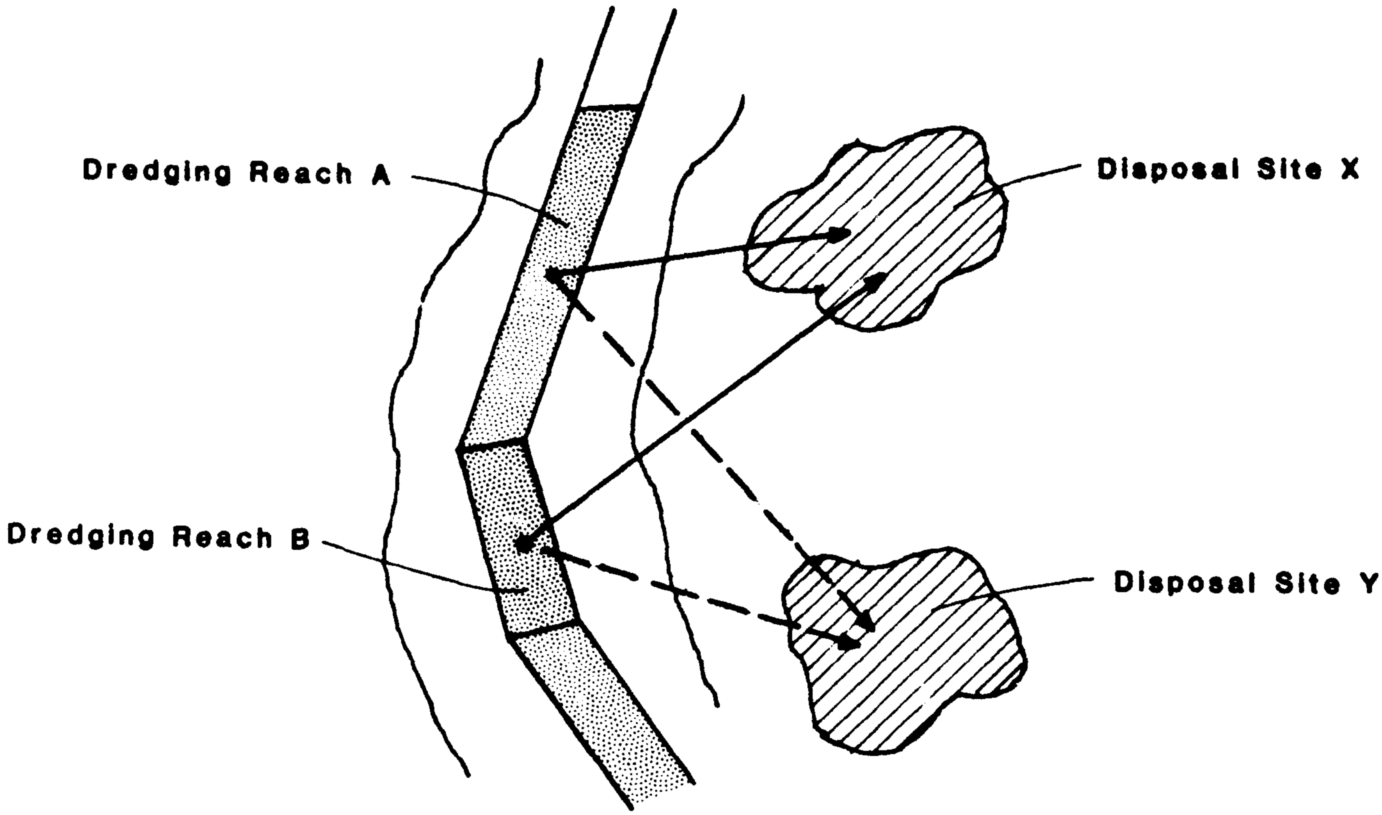
3. What is the least-costly method to provide the additional volume required? Should expired leases be extended or should new sites be acquired?

4. If new sites are to be acquired, what is the least-costly combination of sites? What is the least-costly sequence for acquiring these sites?

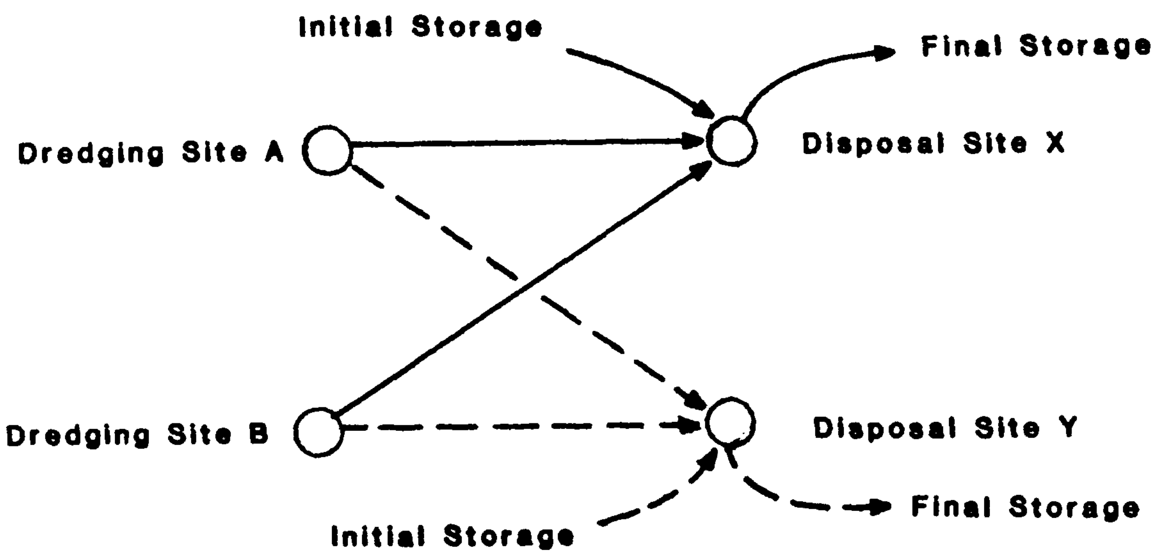
5. Are alternative material-management alternatives, such as transferring material or resting sites, cost effective?

The information is provided by formulating and solving a mathematical programming model in which the disposal system is represented as a network, as illustrated by Fig. 1. The dredging sites and disposal sites are represented by nodes of the network. These nodes are connected by capacitated arcs which represent the facilities for transportation of material in the system. A unit cost is assigned to "flow" each arc, representing the average cost of moving material within the system. For analysis of multiple-period operation, multiple networks are developed and linked in time. Information for answering the capacity expansion questions is provided by systematically formulating and solving network-flow programming problems which represent alterative expansion schemes; the least-costly scheme is identified as the best scheme. Details of model formulation are presented in Appendices I and II.

Input required to use the program includes (1) an estimate of quantity of material dredged at each site each period, (2) a description of physical and economic characteristics of each disposal site, (3) a description of physical and economic characteristics of each material-transportation facility, and (4) specification of any required movement of material within the system. A detailed description of input is presented as Appendix IV.



a) Disposal system



b) Arc-node representation of disposal system

FIG. 1. - Network Representation of Disposal System

BACKGROUND

The Corps of Engineers has been responsible for maintenance of the navigable waterways of the United States since 1824. The maintenance includes excavation and disposal of the sediment deposited in the waterways. Current common practice is to excavate the material with a mechanical or hydraulic dredge and to transport it to a disposal site either by pumping through a pipeline or by carrying the material to the site in barges or in hoppers on the dredge. The disposal site may be an offshore site selected to minimize interference with navigation, or the disposal site may be a contained upland site. Contained disposal sites are natural or man-made ponding areas into which the dredged material is pumped or lifted. In the disposal site, water gradually drains and evaporates from the dredged material, and the solids densify and consolidate. The rate of dewatering, densifying, and consolidating can be increased by surface trenching, wicking, surcharging, or pumping. Detailed descriptions of these techniques and other technical aspects of dredged-material management are presented in Reference 1 and in associated reports of the Corps' Dredge Material Research Program.

Management of the long-term operation of a dredged-material disposal system requires selection of excavating and transporting equipment, allocation of disposal-site capacity, selection of appropriate disposal-site management practices, and identification of capacity expansion schemes. Due to the complexity of the long-term problem, equipment selection and capacity allocation generally is addressed only for the short-term, with equipment and sites selected for minimum cost at the time the dredging is performed. Physical and environmental limitations may constrain this selection and allocation. Likewise, problems of disposal-site operation and of capacity expansion generally are addressed with heuristic rules as problems arise.

PROGRAM CAPABILITIES

The Dredged-material Disposal Management Model (D2M2) is a simulation-optimization model for systematic analysis of long-term operation and expansion of a disposal system. Application of D2M2 requires estimates of volumes dredged, descriptions of the existing and potential disposal sites, and description of the dredging and transporting facilities. With the model, system disposal capacity expansion alternatives can be analyzed, and the minimum-cost disposal-site acquisition and lease extension schedule can be determined. This is accomplished by evaluating automatically the present value of alternative sequences of acquiring new sites and extending leases to identify the least-costly expansion policy. The cost of any alternative capacity expansion plan is considered to be the sum of site acquisition cost, fixed operation, maintenance and repair cost, lease cost, and operation cost. To determine the operation cost, D2M2 includes the capability to identify the minimum-net-cost short-term operation policy for any specified system. This is accomplished by formulating and solving a mathematical programming problem that represents the problem of allocating efficiently the available capacity. If desired, this portion of the program may be used without the capacity expansion evaluation portion.

Disposal-site consolidation rates, containment dike heights, and other characteristics of existing and proposed disposal system components are specified by the model user. Thus, management schemes that involve changes in these parameters may be evaluated by systematic variation and re-execution of the model.

COMPUTATIONAL TECHNIQUES

Program D2M2 employs network-flow programming and a heuristic enumeration scheme to evaluate disposal-system management alternatives. Network-flow programming is used for evaluation of the operation of a specified disposal system. Enumeration is used for selection of the least-costly capacity-expansion scheme.

Network-flow Programming. - Program D2M2 models the characteristics of a system of dredge sites, disposal sites, and material transportation facilities as a network. This network includes nodes that represent the available disposal sites and dredge sites. These nodes are connected by arcs that represent transportation linkages, material-transfer facilities, material-reuse capabilities, and material storage in disposal sites. The flow of material through these arcs represents the transporting, or storing material within the disposal system. A detailed description of this network formulation is presented in Reference 2. A reprint of this reference is included as Appendix I.

A unit cost is associated with the flow in each arc; the objective of the solution algorithm is to determine the allocation of flow to the various network arcs to minimize the sum of the product of flow in each arc and the corresponding cost. The unit costs assigned to the network arcs are the discounted unit costs of storing, transporting, or transferring material or the negative of the unit benefit of reusing material. A specialized network-flow programming algorithm is used to determine the minimum-cost flows. This algorithm is described by Jensen and Barnes (3).

Annotated examples of applications of the network model are presented in Appendix III.

Enumeration. - The least-costly scheme for acquisition of user-specified capacity expansion options is determined in D2M2 by enumeration of a limited number of the possible schedules. Determination of the cost of each schedule is accomplished by computing the sum of the present value of the acquisition costs and lease-renegotiation costs and the present value of operation cost of the disposal system with the expansion sites available. This operation cost is determined with the previously described network model of the disposal system.

The heuristic enumeration procedure incorporated in D2M2 provides for a well-structured, systematic search of the site acquisition and lease renegotiation options. Enumeration begins with evaluation of the total cost if all capacity expansion sites are acquired in the earliest period allowed and if all leases are renegotiated. This capacity expansion scheme is adjusted, based on analysis of disposal site utilization during the period of analysis. After each adjustment, the network model of the disposal system is

altered accordingly, and the least-costly operation policy is found. The cost of acquisition and lease renegotiation for the new expansion scheme is determined and is added to the operation cost. The heuristic rules are again applied, and the process is repeated. This process is described in detail in Appendix II. With careful application of the procedure, acceptable alternative capacity expansion schemes can be identified with reasonable computational effort. One such application is presented in Appendix III as example five.

DATA REQUIREMENTS

Physical and economic characteristics of the dredged-material disposal system must be defined by the user. A detailed description of the input is included as Appendix IV.

Each disposal site must be identified, and the location must be defined as shown in Fig. 2. The distances between disposal and dredge sites are determined from the specified locations and are used to select the appropriate unit transportation cost. The initial conditions of the site, the maximum allowable rate of addition, and an average wet-to-dry ratio for the site must be specified. Constraints on drying the site must be defined, and any fixed disposal rates must be specified. The storage-elevation-surface area relationship must be defined to allow complete reporting of simulated disposal-site operation. If capacity-expansion costs are to be computed, the cost of acquiring, leasing, and maintaining the site must be specified.

Each dredging site must be identified, and the location must be defined consistent with definition of disposal-site location. The estimated volume of material removed each period must be specified, and sites must be identified in which the material can be disposed. The facilities for dredging and transporting material to the disposal sites must be defined.

The dredging and transporting facilities available within the system must be described. A unit-cost vs. distance function must be specified for each transportation facility; the cost of moving material from dredging sites to disposal sites is determined with this function and distances computed from user-specified locations.

HARDWARE AND SOFTWARE REQUIREMENTS

Program D2M2 is written in ANSI standard FORTRAN IV. The program was developed originally on a CYBER 175 computer but has been implemented and is maintained by HEC staff on a Harris 500 computer. Execution of D2M2 requires use of a random access input-output package; such a package is available on most computers. Compilation of D2M2 with the Harris computer requires four central-processor seconds. Execution of the example problems of Appendix II requires 57, 193, 182, 238, and 716 seconds, respectively, and 1.2 million (octal) 24-bit words of virtual memory.

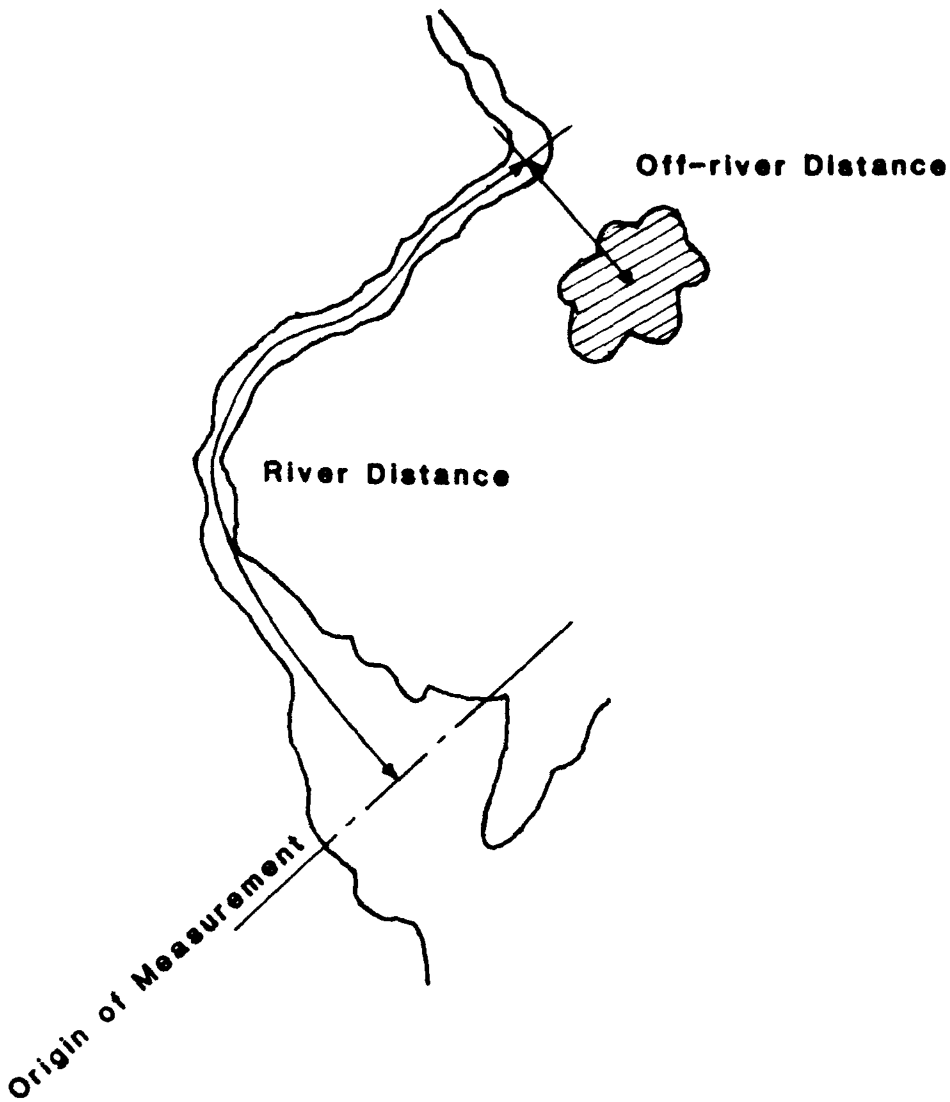


FIG. 2. - Disposal-site and Dredging-site Location Specification

Program D2M2 uses five scratch files. These files are assigned as follows:

File Identification	Use
TAPE5	User input file
TAPE6	Output file
TAPE11	File for storage of capacity-expansion iteration results. Also used for restart input file.
TAPE12	Intermediate file to which user input file is copied.
TAPE99	Direct-access file for network storage

Allocation of available computer memory to the arrays of program D2M2 is problem dependant and is performed automatically by the program. When the dimensions of the disposal system and the period of analysis are defined, an internal algorithm subdivides the memory as necesssary to store characteristics of the disposal sites, dredge sites, and transportation links. Thus operation of a system with many disposal sites and dredge sites can be analyzed for a few time periods, or operation of a small system can be analyzed for many time periods. The limitations on disposal system size and period of analysis are presented in Appendix IV for the distributed Harris 500 version of the progam; users may modify program dimensions to implement the program on other computers.

ERROR IDENTIFICATION

As the input for program D2M2 is read, the user-specified values are compared with expected ranges or allowable values. If an error is detected, a message is printed. These messages, which are self-explanatory, are listed in Table 1. Errors are classified as fatal or non-fatal. If a fatal error is discovered, program execution terminates. If a non-fatal error is detected, a default or maximum value is used instead of the user-specified value, a message indicating this is printed, and execution continues.

ORIGIN OF PROGRAM

Program D2M2 was developed originally in the Hydrologic Engineering Center (HEC) with financial and technical assistance from the Philadelphia District, Corps of Engineers. Subsequent modifications were funded by the Philadelphia District and the Dredging Divison of the Water Resources Support Center through the Waterways Experiment Station, Corps of Engineers. The software was developed by Rochelle Barkin and the network model and the branch-and-bound algorithm were formulated by David Ford and Darryl Davis, Chief, Planning Analysis Branch. Dr. Ford managed program development and supervised preparation of this manual. The subroutines for solution of the network-flow programming problem were provided by Quentin Martin of the Texas Department of Water Resources; Dr. Martin provided assistance with application of these subroutines. Brian Heverin and William W. L. Lee of the Philadelphia District assisted with model testing and provided valuable technical guidance. Bill S. Eichert was Director of the HEC during model development.

Table 1. - Error Messages

Fatal Error Messages

Message	User Action
TOO MANY TRANSPORTATION LINKS, DREDGE SITES, DISPOSAL SITES, OR TIME PERIODS. <Equation for program maximum>. CALCULATED = <value calculated for user defined system> MAXIMUM = <program maximum>	Reduce number of transportation links, dredge sites, disposal sites, or time periods. See input description for maximum.
TOO MANY NODES IN MODEL. <Equation for program maximum>. CALCULATED = <user value>, MAXIMUM = <program maximum>	Reduce number of disposal sites, dredge sites or time periods, as indicated by equation.
<id> CARD EXPECTED. <id> CARD READ.	Consult input guide for sequence of cards.
LATEST ACQUISITION DATE OMITTED FOR EXPANSION SITE <site id>.	Specify latest acquisition date, field 3 of SX card.
CARD NO. <number> THE VALUE OF IEXP (<user-specified value>) IS INVALID	Replace value in field 1 of specified card with 0, 1, 2, or 3.
TOO MANY ARCS ENCOUNTERED IN PERIOD <period number>	Reduce number of dredge sites, number of disposal sites, or number of transportation links that originate or terminate at disposal sites.
INSUFFICIENT AMORTIZATION PERIODS	The latest period specified for possible acquisition of this capacity expansion site will not permit proper amortization. Decrease number of periods required (field 9 of J1 card) or increase latest period (field 3 of SX card).
CARD NO. <number> HAS INVALID DREDGE SITE ID = <alphanumeric identifier>	Replace identifier on specified card with one of identifiers defined on DI cards.

Message	User Action
CARD NO. <number> HAS INVALID DISPOSAL SITE ID = <alphanumeric identifier>	Replace identifier with one defined on SI cards.
CARD NO. <number> HAS INVALID TRANSPORTATION SITE ID = <alphanumeric identifier>	Replace identifier with one defined on TI cards.
THE DISTANCES OF THE DISTANCE-UNIT COST FUNCTION (<transportation-type identifier>) ARE NOT INCREASING	Re-arrange values on TD cards. Values on TC card must correspond.
THE UNIT COSTS OF THE DISTANCE-UNIT COST FUNCTION(<transportation-type identifier>) ARE NOT INCREASING	Re-arrange values on TC card. Values on TD card must correspond.

Non-Fatal Error Messages

THE VALUE OF NPER (<user-specified value>) ON THE J1 CARD IS GREATER THAN THE MAXIMUM (<maximum allowable value>) NPER SET EQUAL TO MAXIMUM	Reduce NPER (field 1 of J1 card) or accept maximum.
THE VALUE OF DRATE (<user-specified value>) ON THE J1 CARD IS INVALID. DRATE SET EQUAL TO DEFAULT (1)	Accept default or specify $0 < \text{DRATE} \le 100$.
THE VALUE OF VMULT (<user-specified value>) ON THE DL CARD NO. <card number> IS INVALID. VMULT SET EQUAL TO DEFAULT (1.0)	Accept default or specify VMULT > 0.
THE VALUE OF WDRAT (<user-specified value>) ON THE SL CARD NO. <card number> IS INVALID. WDRAT SET EQUAL TO DEFAULT (1.0)	Accept default or specify wet-to-dry ratio (WDRAT) > 0.
THE VALUE OF NREHND (<user-specified value>) ON THE SR CARD NO. <card number> IS INVALID. NREHND SET EQUAL TO DEFAULT (2)	Accept default or specify $\text{NREHND} \le 2$.
READIN -- NEXT IDENTIFICATION CODE IS INVALID, RECORD IGNORED	Check card for keypunch error.

REFERENCES

1. Corps of Engineers, U.S. Army, "Dredged Material Research Program Executive Overview and Detailed Summary," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, December, 1978.

2. Ford, D.T., "Dredged-material Disposal Management Model," Journal of the Water Resources Planning and Management Division, ASCE, Vol. 16, No. 1, Jan., 1984, pp. 57-74 (available also as Hydrologic Engineering Center Technical Paper No. 94).

3. Jensen, P.A., and Barnes, J.W., Network Flow Programming, John Wiley and Sons, Inc., New York, N.J. 1980.

Dredged-Material Disposal Management Model

By David T. Ford,[1] M. ASCE

Abstract: To identify efficient dredged-material disposal management strategies for the Delaware River navigation system near Philadelphia, the system operation problem is formulated and solved as a generalized minimum cost network flow programming problem. This formulation represents material sources and available disposal sites as nodes of the network and transportation links and carry-over storages as arcs. The dewatering, consolidation, and densification of dredged material is modeled with an arc gain factor, thereby allowing reduction of the total volume of material within the network but requiring use of a network-with-gains algorithm for solution of the operation problem. Application of the model defines cost-efficient dynamic schemes for allocation of material to available disposal sites. A generalized computer program was developed to define automatically the nodes, arcs, and parameters of the arcs of the network, given a description of the dredged-material disposal system. Structured analysis and structured programming techniques were used, thus providing a clear definition of the computations required, the order in which they must be accomplished, and the flow of data. This software development technique reduces the effort required for subsequent modification of the program to analyze the system capacity-expansion problem.

Delaware River Disposal Management Problem

Background.—The Corps of Engineers has been responsible for maintenance of the navigable waterways of the United States since 1824. The maintenance includes excavation and disposal of the sediment deposited in the waterways. Current common practice is to excavate the material with a mechanical or hydraulic dredge (10) and to transport it to a disposal site either by pumping through a pipeline or by carrying the material to the site in barges or in hoppers on the dredge. The disposal site may be an offshore site selected to minimize interference with navigation or the disposal site may be a contained upland site. Contained disposal sites are natural or manmade ponding areas into which the dredged material is pumped or lifted. In the disposal site, water gradually drains and evaporates from the dredged material, and the solids densify and consolidate. The rate of dewatering, densifying, and consolidating can be increased by surface trenching, wicking, surcharging, and pumping with well pants. Detailed descriptions of these techniques and other technical aspects of dredged-material management are presented in Ref. 3 and in associated reports of the Corps' Dredged Material Research Program.

Management of the long-term operation of a dredged-material disposal system requires selection of the equipment to be used for excavating and transporting the material from the channel to the disposal sites, allocation of the capacity of the available disposal sites to satisfy

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Note.—Discussion open until June 1, 1984. To extend the closing date one month, a written request must be filed with the ASCE Manager of Technical and Professional Publications. The manuscript for this paper was submitted for review and possible publication on October 14, 1982. This paper is part of the *Journal of Water Resources Planning and Management*, Vol. 110, No. 1, January, 1984. ©ASCE, ISSN 0733-9496/84/0001-0051/$01.00. Paper No. 18526.

the demand for storage imposed by the dredging operation, selection of appropriate disposal-site management practices, and identification of capacity expansion schemes if the system capacity is exhausted at some time. Due to the complexity of the long-term problem, equipment selection and capacity allocation generally is addressed only for the short-term, with equipment and sites selected for minimum cost at the time the dredging is performed. Physical and environmental limitations may constrain this selection and allocation. Likewise, problems of disposal-site operation and of capacity expansion generally are addressed with heuristic rules as problems arise.

Delaware River System.—The Delaware River, Delaware Bay, and associated tributaries are maintained in a navigable condition by the Philadelphia District, Corps of Engineers. Within this area, shown in Fig. 1, 23 Federal navigation projects yield approximately 8,100,000 cu yd (6,200,000 m^3) of dredged material annually. Non-Federal maintenance dredging contributes an additional 3,400,000 cu yd (2,600,000 m^3). The material is disposed in 21 containment sites. According to estimates published in a 1979 study, by 1999 all these sites will be filled or unavailable due to lease expiration with continued maintenance dredging at current

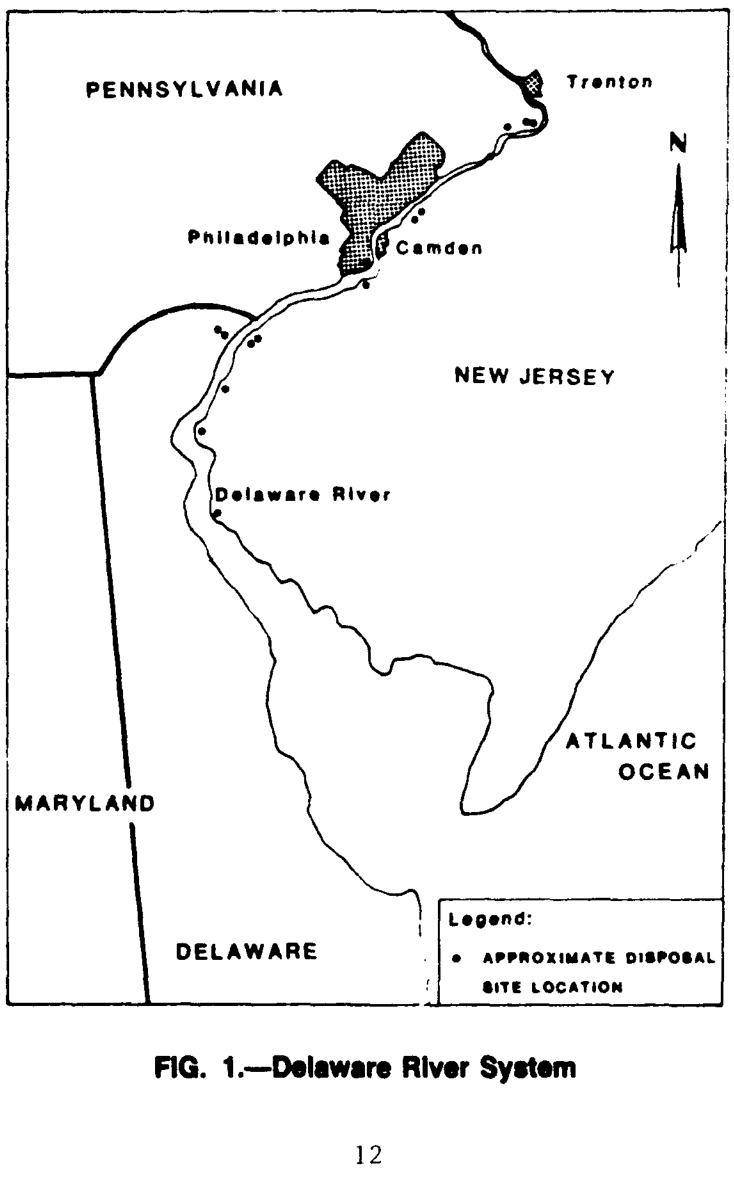

FIG. 1.—Delaware River System

rates and with no change in management practices (4). This in turn would mean reduction or cessation of dredging and consequent reduction or cessation of navigation. The 1979 study identifies a number of management alternatives that may be employed, including:

1. Capacity expansion alternatives: (a) Acquisition of new upland sites; (b) open-water disposal of dredged material; and (c) extension of leases on sites.
2. Operation alternatives: (a) Dewatering of disposal sites; (b) increase in containment dike height; (c) reuse of dredged material; (d) reduction of maintenance dredging; (e) use of deposition basins to reduce shoaling; (f) reduction of sediment erosion; and (g) improvements in site management.

Management Model Description

Model Objective.—The dredged-material disposal management model was developed for systematic evaluation of and comparison of alternative management schemes. With the model, capacity expansion alternatives can be analyzed, and the minimum-cost combination and schedule can be determined for new site acquisition and lease extension. Also, the minimum-net-cost operation policy for any specified system can be determined. This policy is required both for long-term system operation planning and for solution of the expansion problem; the total cost of any alternative capacity expansion scheme is a function of site acquisition, lease extension, and operation costs. The minimum operation cost and the associated operation policy are determined by formulating a mathematical programming model that represents the problem of allocating efficiently the available capacity. Disposal-site dewatering rates, containment dike heights, and other characteristics of the disposal system are specified by the model user, so management schemes that involve changes in these parameters are evaluated by systematic variation and re-execution of the model.

Initial development of the disposal management model is limited to formulation of the mathematical programming model presented herein for analysis of operation of a defined system. Ultimately the model will be expanded to address the capacity expansion problem, using a branch-and-bound algorithm which iteratively enumerates a limited number of alternative site acquisition and lease renegotiation schemes, evaluates the efficiency and feasibility with the operation model, and identifies efficient schemes for expanding the system. The branch-and-bound procedure provides rules for eliminating from consideration many costly or infeasible schemes without actual evaluation with the operation model.

Mathematical Programming Formulation.—The mathematical programming formulation of the dredged-material disposal system operation problem includes continuity constraints for material sources and for disposal sites, transportation link and disposal-site capacity constraints, and carry-over storage constraints. The continuity and capacity constraints define the operation problem for each period. The carry-over storage constraints relate conditions within each period, yielding a multiperiod operation problem. Unit costs are associated with transportation

and disposal of dredged material. The objective is to minimize the total discounted cost of system operation. This formulation is similar to the solid-waste disposal model formulated by Marks and Liebman (13) and to the wastewater disposal model formulated by Brill and Nakamura (2).

A continuity constraint is included for each material source and for each disposal site for each period of analysis. The form of the equation for each material source, I, for each period T is

$$\sum_{J=1}^{\mathrm{NDISP}} F(I,J,T) = V(I,T) \quad \text{(1)}$$

in which J = index of disposal sites; NDISP = total number of disposal sites; $F(I,J,T)$ = volume of material transported from source I to site J in period T; and $V(I,T)$ = total volume of material dredged at source I during period T. The form of the equation for each disposal site J for each period T is

$$S(J,T-1) + \mathrm{VF}(J)^{*}\left[\sum_{I=1}^{\mathrm{NDRG}} F(I,J,T)\right] + \left[\sum_{\substack{J'=1 \\ J' \neq J}}^{\mathrm{NDISP}} \mathrm{RT}(J',J,T) - \mathrm{RT}(J,J',T)\right] - \mathrm{RU}(J,T) = S(J,T) \quad \text{(2)}$$

in which NDRG = total number of dredged-material sources; $S(J, T - 1)$ = volume of material stored at site J at beginning of period T and at the end of period $T - 1$; $S(J,T)$ = volume of material stored at site J at end of period T; RT (J,J',T) = volume of material transferred to site J from site J'; RT (J',J,T) = volume of material transferred from site J to site J' in period T; RU (J,T) = volume of material from site J removed and sold for reuse; and VF (J) = an average volume-reduction factor. The volume reduction factor reflects: (1) The wet-to-dry volume ratio of the dredged material; and (2) the efficiency of the disposal site management practices. The wet-to-dry volume ratio defines the average volume of dry material per time period that must be stored at the disposal site as a fraction of the total volume of material in situ. E.g., a wet-to-dry ratio of 2.0 indicates that the dredged material, when wet, will occupy twice the volume occupied by the dried material. In this formulation the volume reduction is assumed to occur within one period. The efficiency of the disposal site in terms of achievement of the reduction depends on the site management techniques. If the techniques employed are 100% efficient, VF (J) will equal the reciprocal of the wet-to-dry ratio; otherwise, VF (J) will equal the product of this reciprocal and the estimated efficiency of the dewatering techniques used at the site. Typical values of VF (J) range from 0.50 to 1.00.

The total volume of material to be transported to or from a disposal site is constrained by the characteristics of the pipeline, hopper, or other device used for transportation. Likewise, the volume of material deposited at a site each period T is constrained by the size of the site. These limitations are expressed mathematically as

$$F(I,J,T) \leq \mathrm{FMAX}(I,J) \quad \text{(3)}$$

$$RT(J,J',T) \leq RTMAX(J,J') \quad (4)$$

$$RU(J,T) \leq RUMAX(J) \quad (5)$$

$$S(J,T) \leq SMAX(J) \quad (6)$$

in which $FMAX(I,J)$ = capacity of the transportation link between dredged-material source I and disposal site J; $RTMAX(J,J')$ = capacity of the facilities for removing material from disposal site J and transferring it to site J'; $RUMAX(J)$ = capacity of the facilities for removing material from disposal site J for reuse; and $SMAX(J)$ = storage capacity of disposal site J.

In addition to the restrictions on transportation, disposal-site management practices may pose a limitation on the rate of addition of "wet" material to the site. This limitation is imposed each period by the following constraint:

$$\sum_{I=1}^{NDRG} F(I,J,T) \leq ADDMAX(J) \quad (7)$$

in which $ADDMAX(J)$ = maximum allowable volume addition per period.

The operation problem is to determine the "best" scheme for allocating the material dredged each period to the available sites over the planning horizon. The efficiency of operation is defined as the algebraic sum of the present value of costs of disposal and transportation and the benefits of reuse. Mathematically, this is expressed as

$$Z = \sum_{T=1}^{NPERS} (1+R)^{-T} \left[\left\{ \sum_{I=1}^{NDRG} \sum_{J=1}^{NDISP} CF(I,J) * F(I,J,T) \right\} + \left\{ \sum_{J=1}^{NDISP} CS(J) * \sum_{I=1}^{NDRG} F(I,J,T) \right\} + \left\{ \sum_{J=1}^{NDISP} \sum_{\substack{J'=1 \\ J' \neq J}}^{NDISP} CRT(J,J') * RT(J,J',T) \right\} - \left\{ \sum_{J=1}^{NDISP} CRU(J) * RU(J,T) \right\} \right] \quad (8)$$

in which Z = the present value of system net benefits for the period of analysis; R = discount rate; NPERS = number of time intervals; $CF(I,J)$ = unit cost of transporting material from dredge site I to disposal site J; $CS(J)$ = unit cost of adding material to disposal site J; $CRT(J,J')$ = unit cost of removing material from site J, transporting to and disposing in site J'; and $CRU(J)$ = unit benefit of reuse of material from site J. These costs and benefits are assumed to be constant over time. The objective is minimization of the net cost, Z.

Mathematical Programming Problem Solution.—The dredged-material system operation model as presented includes linear constraints and a linear objective function, so a linear programming (LP) algorithm can be used to determine the optimal allocation of dredged material to the available sites. However, the constraints define only conservation requirements and transportation limitations, and the costs and benefits are functions of the volume of material transported or stored, so the oper-

ation problem can be formulated as a network-flow programming problem. In a network-flow problem, the decisions required are visualized as flows in the arcs connecting the nodes of a network, and the objective is to choose the flow in each arc to optimize some efficiency measure, such as total cost. The arcs of the network are characterized by the allowable direction of flow, the maximum and minimum amounts of flow that can pass through each arc, the unit cost of use of the arc, and a gain that represents the fraction of flow that is lost (or gained) in each arc. The constraints are limited to conservation of flow at the nodes of the network and to upper and lower bounds on flows in the arcs. Algorithms for solution of the network-flow problems are more efficient than those for solution of the general LP problems. Ford and Fulkerson (8) and Jensen and Barnes (12) provide detailed descriptions of the characteristics of network-flow problems.

The network-flow model of the disposal operation problem represents material sources and available disposal sites as nodes and transportation links and carry-over storage as arcs. The network representation of a small disposal system is shown as Fig. 2. Nodes 1 and 2 represent the Pedricktown North disposal site, nodes 3 and 4 represent the Pedricktown South site, and nodes 5 and 6 represent Overflow Site 1. Nodes 7, 8, and 9 represent the Marcus Hook, Bellevue, and Cherry Island dredge sites, respectively. The arcs connecting nodes 7, 8, and 9 with nodes 1, 3, and 5 represent the transportation links between the material sources and disposal sites. The "flows" in these arcs represent the volumes of material allocated to the disposal sites. For a more complex system, arcs are included to connect each source with each site available for disposal of the material from that source. An upper bound is imposed on flow in these arcs, as dictated by the transportation method represented.

Removal of material from the disposal sites for reuse is represented by an arc originating at the disposal site node and terminating at a node

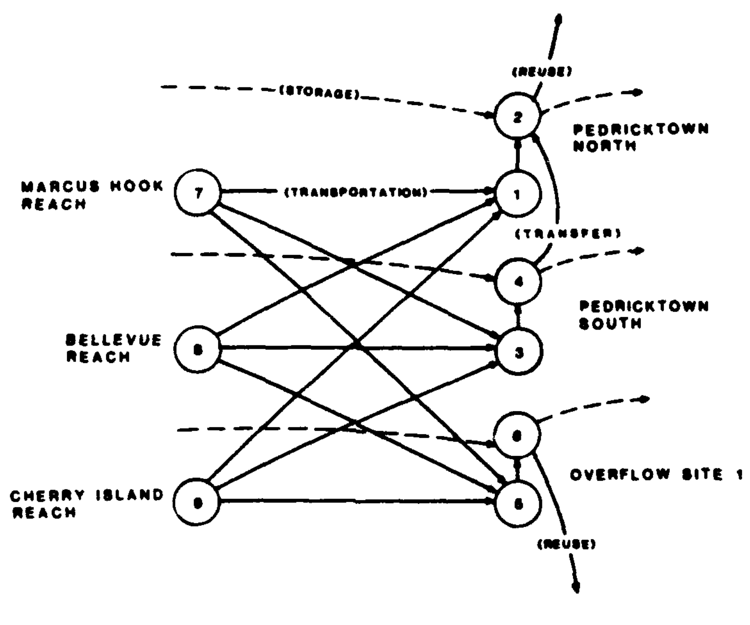

FIG. 2.—Single-Period Example of Network Representation

that represents the point of sale of the reused material. Material removed from the Pedricktown South site and transferred to the Pedricktown North site is represented by flow in the arc originating at node 4 and terminating in node 2.

The arc originating at node 1 and terminating at node 2, the arc originating at node 3 and terminating at node 4, and the arc originating at node 5 and terminating at node 6 are included as a computational mechanism to represent the drying of material added to a disposal site and to limit the rate of addition of material to the site. The gains for these arcs are the volume reduction factors [VF(J) of Eq. 2], and the upper bounds are the maximum allowable rates of disposal [ADDMAX(J) of Eq. 7].

Material is introduced to the network at the nodes that represent the dredged-material sites. In the terminology of Jensen and Barnes (12), these volumes are node external flows; the quantity of flow entering the network is fixed.

The dashed arcs of Fig. 2 represent the storage of material in the system disposal sites. The flow in the storage arc that terminates at node 2 represents the net volume of dried material deposited in the Pedricktown North site in all periods prior to the current period [$S(J, T-1)$ of Eq. 2]. The storage arc originating at node 2 represents the cumulative volume of dried dredged-material deposited in the site after the addition and removal of material in the period shown [$S(J, T-1)$ of Eq. 2]. When the network is expanded for analysis of multiple-period operation, these storage arcs link the networks that represent single-period problems. This is shown in Fig. 3.

A unit cost is associated with the flow in each arc; the objective of the solution algorithm is to determine the allocation of flow to the various network arcs to minimize the sum of the product of flow in each arc and the corresponding cost. The unit costs assigned to the network arcs are the discounted units costs of storing, transporting, or rehandling material [CS(J), CF(I,J), and CRT(J,J') of Eq. 8] and the negative of the unit benefit of reuse [CRU(J)].

The traditional network flow programming solution algorithms, such as the out-of-kilter algorithm (5,7,9) were developed for problems in which

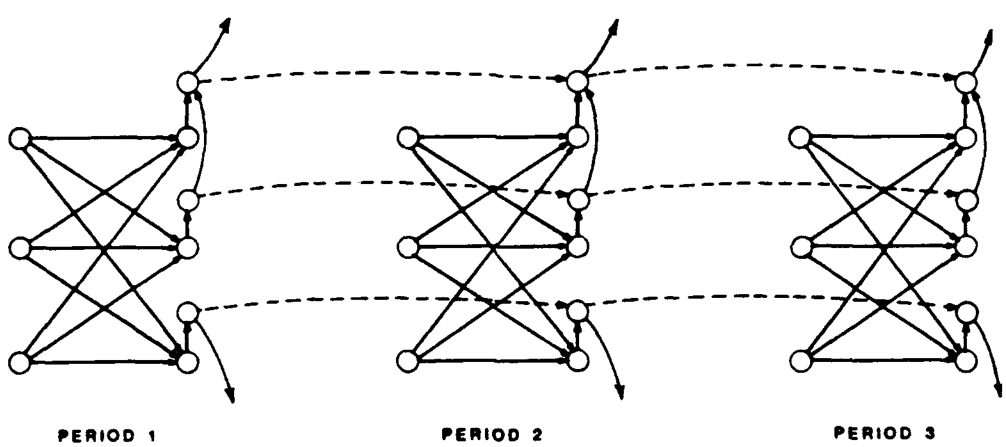

FIG. 3.—Multiple-Period Network Representation

all gain factors are unity and, thus, are not applicable. Consequently, for solution of the management problem as formulated, a specialized network-with-gains algorithm is employed. This algorithm solves the generalized minimum-cost network flow problem with any nonnegative gain factors using a flow-augmentation algorithm. In this application, the algorithm begins with flow in all arcs set equal to zero. The minimum cost per unit of additional flow to each node of the network and the path over which that flow may be obtained is determined. The total flow through the network is increased along the minimum-cost path until the flow in one or more arcs in the path exceeds the bounds. This process continues iteratively until the required system input flows are satisfied or a maximum possible flow through the network is obtained. This algorithm guarantees achievement of a feasible, global optimal solution if such a solution exist. Additional details of the algorithm are presented by Jensen and Bhaumik (11) and by Jensen and Barnes (12); a previous application of the algorithm is described in Ref. 14.

Software Development

A generalized computer program was developed to implement the proposed disposal-system management model to evaluate alternative system capacity expansion plans. The program development employed state-of-the-art software engineering techniques, including structured analysis and structured programming (1).

Structured Analysis.—Structured analysis is a logical process for transforming information about program requirements into specifications for the program that is to be developed. This approach is contrary to usual engineering program development activities in which everyone eagerly gets on to the "real" work—writing code. As described by Demarco (6), the structured analysis approach has the following characteristics: (1) It yields a paper model of the program-to-be; (2) the pro-

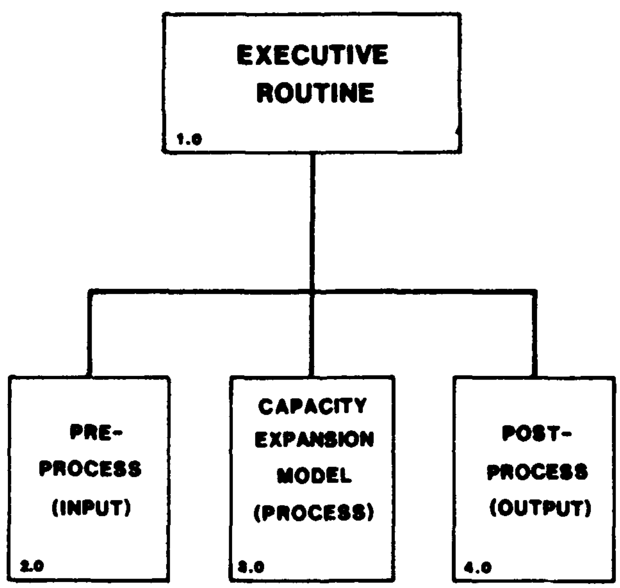

FIG. 4.—Top Level of Control

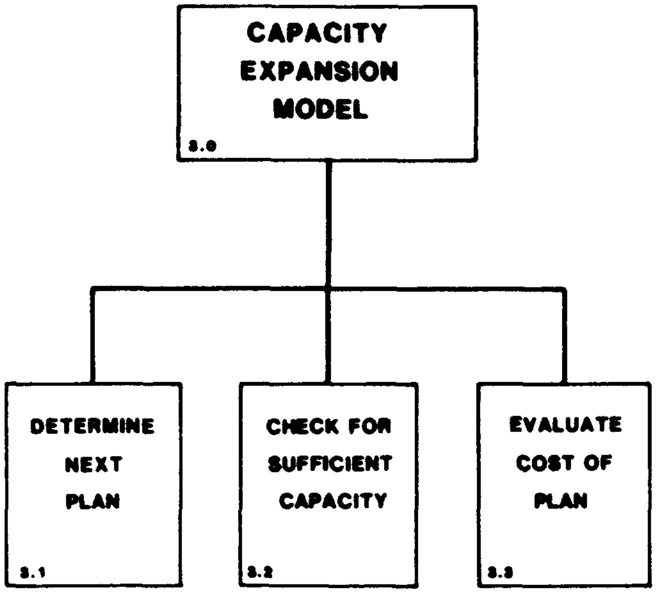

FIG. 5.—Capacity Expansion Component

gram is designed in a top-down, hierarchical fashion with a smooth progression from abstract definition of program components to a detailed definition; (3) it yields a set of connected "mini-specifications" of the identified program components; and (4) it uses diagrams for communication of ideas, especially between the program user, program designer, and computer system analyst.

Top-down program design begins with the establishment of firm requirements for the tasks to be accomplished by the program and with the definition of data required to accomplish the tasks. The overall program structure (top-level) is then defined, with progressive refinement of lower-level components of the program. Fig. 4 shows the organization of the top level of the dredged-material disposal management program.

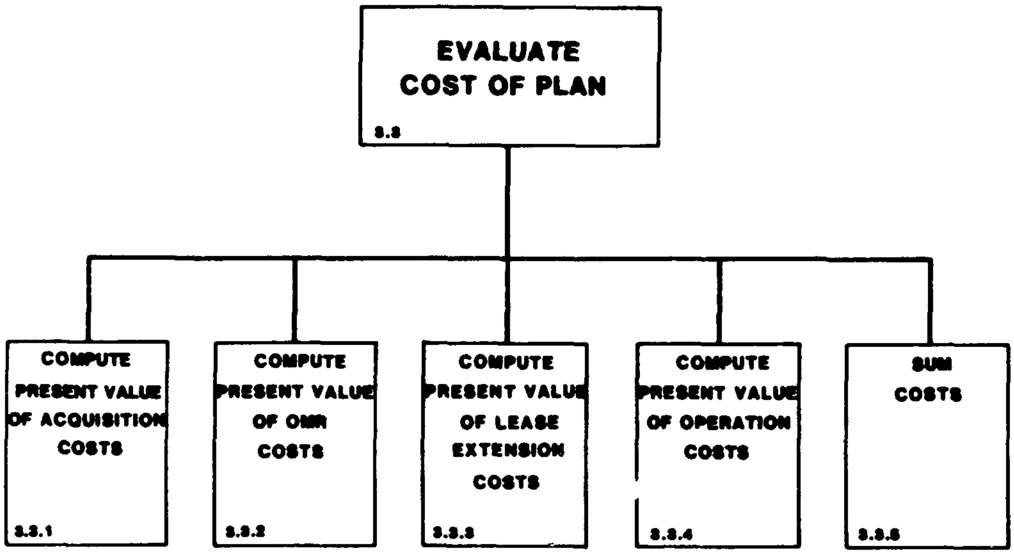

FIG. 6.—Cost Evaluation Component

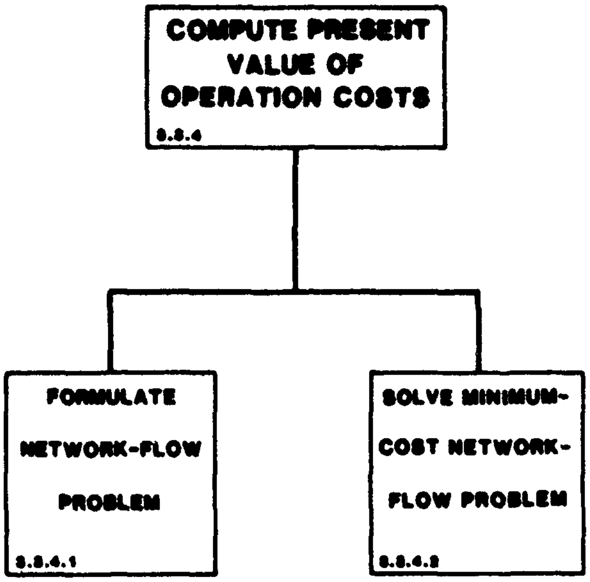

FIG. 7.—Operation-Cost Evaluation Component

The program consists of an "executive" routine controlling an "input," a "process," and an "output" routine. Figs. 5 and 6 show further refinement of the process component; specification of the other components is refined in a similar manner. Development of the system management model was planned (and funded) for completion in two separate stages: stage 1 includes only the operation model development, while stage 2 addresses the capacity expansion problem in more detail. In stage 1, several of the components shown were defined only in conceptual terms. For example, detailed specification of computational techniques was delayed initially in the case of component 3.1. Nevertheless, the data transfers and the required results of execution of each module were defined.

The network-flow programming model formulated to determine the optimal allocation of dredged material is identified as component 3.3.4 in Figs. 6 and 7. As one of the goals of program development is to produce a management model usable by engineers and planners who are not familiar with mathematical programming techniques, component 3.3.4.1 is included here to translate disposal-system descriptive data into the node-arc representation. The resulting generalized minimum-cost network-flow problem is solved with code included in component 3.3.4.2. Definition of this component is further refined to include components of the network-with-gains algorithm.

Structured Programming.—The actual computer code to implement the disposal management model was developed from the structured analysis using structured programming techniques. Each of the components was translated into one or more subprograms that perform independently single tasks required for solution of the operation problem. The benefits of this approach are: (1) The actual development time is reduced because a number of programmers may simultaneously develop the modules, or existing code may be used easily; (2) complex programs may be tested in parts, with each module verified independently; (3) the

code is easier to understand and to maintain; (4) the resulting code is flexible and may be modified by changing single modules independently; and (5) documentation of the code is easier. Items 3, 4, and 5 are significant given the environment within which the computer code described here will be used. Although a single application motivated development, application to other disposal operation problems is likely and despite careful program design, past experience indicates a frequent need for special-case modification. Often these modifications must be performed by someone other than the original program writer, thus the need for understandable code.

APPLICATION

Operation Evaluation.—The operation model has been used to evaluate the operation of various existing and proposed configurations of the Delaware River dredged-material disposal system, including the subsystem between Philadelphia and the sea. As modeled, this subsystem includes 19 dredge sites and 8 disposal sites (of which two are imaginary sites for overflow if the system capacity is insufficient). Pertinent data describing the disposal sites are presented in Table 1. Material is dredged at average annual rates shown in Table 2 and is transported by barge, hopper, or pipeline to the disposal sites. The dredging and transporting costs depend on the machinery used and the distance which the material is transported; costs vary from \$1.62 to \$25.00/cu yd and are shown in Table 3. The unit costs of placing the material in the system disposal sites vary from \$0.00 to \$0.50/cu yd, as indicated in Table 1.

The operation of the Philadelphia-to-sea subsystem was analyzed for 50 yr using 25 consecutive 2-yr intervals. The resulting network consisted of 877 nodes and 3,709 arcs. Time required for definition of the network parameters and for solution of the minimum-cost optimization program on a commercial Cyber 175 computer system used by the Corps was approximately 59 CP sec. The minimum present-value net cost for system operation with an annual discount rate of 7-5/8% is $\$273 \times 10^6$.

Figs. 8–11 are reproductions of portions of the computer program output. Fig. 8 is a summary of the dimensions of the system to be analyzed.

TABLE 1.—Disposal Site Information

Disposal site (1)	Capacity remaining, in cubic yards (2)	Wet-to-dry ratio (3)	Disposal cost, in dollars per cubic yard (4)
Artificial Island	16,500,000	1.50	0.32
Overflow Site 1	99,000,000	1.00	0
Overflow Site 2	99,000,000	1.00	0
National Park	7,100,000	1.50	0.50
Killcohook	36,900,000	1.50	0.11
Penns Neck	16,000,000	1.50	0.25
Pedricktown North	21,700,000	1.50	0.16
Pedricktown South	21,700,000	1.50	0.17

Note: 1 cu yd = 0.765 m^3; 1 acre = 0.405 ha.

TABLE 2.—Dredging Rate, in Cubic Yards per Year

Dredge site (1)	Volume (2)
Eddystone	12,300
Chester	890
Marcus Hook	1,850,300
Bellevue	49,900
Cherry Island	180,900
Deepwater Point	1,402,900
Bulkhead Bar	28,700
Newcastle	1,269,400
Reedy Island	28,000
Baker	10,800
Liston	220,800
Miah Maull	41,000
Brandywine	1,500
W. Horseshoe	25,800
Mifflin	67,400
Billingsport	5,600
Tinicum	43,200
Upper Philadelphia Harbor	6,500
Lower Philadelphia Harbor	181,500

Note: 1 cu yd = 0.765 m^3.

TABLE 3.—Dredging and Transporting Cost, in Dollars per Cubic Yard

	Disposal Site							
Dredge Site (1)	Artificial Island (2)	Overflow Site 1 (3)	Overflow Site 2 (4)	National Park (5)	Killcohook (6)	Penns Neck (7)	Pedricktown North (8)	Pedricktown South (9)
Eddystone	6.99	25.00	25.00	17.89	*	*	2.83	3.06
Chester	6.57	25.00	25.00	*	*	*	2.42	2.65
Marcus Hook	6.12	25.00	25.00	17.01	*	*	1.99	2.22
Bellevue	4.91	25.00	25.00	*	*	2.47	2.09	1.86
Cherry Island	*	25.00	25.00	15.40	*	2.08	2.48	2.25
Deepwater Point	3.57	25.00	25.00	*	2.01	1.95	*	3.23
Bulkhead Bar	3.16	25.00	25.00	*	1.61	2.35	*	*
Newcastle	2.48	25.00	25.00	*	1.98	3.02	*	*
Reedy Island	1.62	25.00	25.00	*	2.84	3.90	*	*
Baker	1.63	25.00	25.00	*	3.25	4.29	*	*
Liston	2.22	25.00	25.00	*	3.85	4.86	*	*
Miah Maull	7.25	19.25	19.25	*	8.88	9.94	*	*
Brandywine	8.70	15.24	15.24	*	10.33	11.36	*	*
W. Horseshoe	8.56	25.00	25.00	19.30	*	*	4.37	4.60
Mifflin	8.09	25.00	25.00	19.02	*	*	3.93	4.15
Billingsport	7.85	25.00	25.00	18.78	*	*	3.69	3.93
Tinicum	7.23	25.00	25.00	18.14	*	*	3.07	3.31
Upper Philadelphia Harbor	9.69	25.00	25.00	19.30	*	*	5.50	5.75
Lower Philadelphia Harbor	9.24	25.00	25.00	19.30	*	*	5.29	5.04

Note: * Indicates sites not linked (1 cu yd = 0.765 m^3).

BASIC DATA

NUMBER OF PERIODS OF ANALYSIS..	25	NUMBER OF DISPOSAL SITES........	8
FIRST PERIOD..................	1	NUMBER OF DREDGE SITES..........	19
DISCOUNT RATE PER PERIOD.......	15.76	NUMBER OF TRANSPORTATION TYPES..	4
MAXIMUM NUMBER OF ITERATIONS...	0	OUTPUT CONTROL VARIABLE.........	0
NUMBER OF AMORTIZATION PERIODS.	10		

TRANSPORTATION DATA

ID = HOPGOV — GOVERNMENT HOPPER DREDGE

	1	2	3	4	5	6	7	8	9	10
DISTANCE	5280.00	52800.00	79200.00	105600.00	158400.00	211200.00	264000.00	316800.00	422400.00	528000.00
UNIT COST	1.40	3.00	3.90	4.75	6.60	8.40	10.20	11.95	15.60	19.30

ID = 27PIPN — 27-INCH CONTRACT PIPELINE DREDGE

	1	2	3	4	5	6	7	8	9	10
DISTANCE	1000.00	5500.00	10950.00	11000.00	21950.00	22000.00	32950.00	33000.00	105600.00	0.00
UNIT COST	.65	.90	1.50	2.10	2.55	3.00	3.60	4.10	15.00	0.00

ID = BUCK12 — 12CY BUCKET DREDGE

	1	2	3	4	5	6	7	8	9	10
DISTANCE	5280.00	47520.00	52800.00	100320.00	105600.00	179520.00	184800.00	311520.00	316800.00	528000.00
UNIT COST	4.10	4.10	4.40	4.40	4.70	4.70	4.90	4.90	5.20	25.00

ID = BUC12R — 12CY BUCKET DREDGE WITH REHANDLING

	1	2	3	4	5	6	7	8	9	10
DISTANCE	5280.00	47520.00	52800.00	100320.00	105600.00	179520.00	184800.00	311520.00	316800.00	528000.00
UNIT COST	5.35	5.35	5.65	5.65	5.95	5.95	6.15	6.15	6.45	25.00

FIG. 8.—System Dimensions and Transportation Cost Report

Also, for each type of dredge, a function relating the unit excavating and transporting cost to distance transported is presented. Fig. 9 is one of 8 disposal site reports. In this report, the physical and economic characteristics of the disposal site are summarized. Site acquisition and lease renegotiation data are included for future use when the program is expanded to address the capacity expansion problem. Fig. 10 is one of 19 dredge site reports for this system. The alternative sites for disposal of

ID = KILLCO — KILLCOHOOK DISPOSAL SITE

LOCATION		STORAGE DATA	
MAIN STEM RIVER DISTANCE.......	215000.00	INITIAL STORAGE.............	0.00
OFF MAIN STEM DISTANCE.........	7000.00	WET-TO-DRY RATIO............	1.50
OFF RIVER TRANSPORTATION TYPE..		MAXIMUM ADDITION/PERIOD.....	36900000.
		DISPOSAL COST...............	.11
SITE ACQUISITION DATA		LEASE DATA	
ACQUISITION COST...............	0.	END-OF-LEASE PERIOD.........	26
EXPANSION INDICATOR............	1	RENEGOTIATION COST..........	0
EARLIEST ACQUISITION PERIOD....	1		
LATEST ACQUISITION PERIOD....	1		
REUSE DATA		FIXED O,M+R COST PER PERIOD......	10000.
FIRST PERIOD AVAILABLE.........	0		
MAXIMUM ALLOWABLE RATE.........	0.00		
UNIT BENEFIT...................	0.00		
TRANSFER DATA		NUMBER OF TRANSFER SITES =	0

	1	2	3	4	5	6	7	8	9
CAPACITY	0.	100000.	200000.	3900000.	16900000.	36900000.	36900000.	36900000.	36900000.
ELEVATION	0.00	16.00	20.00	30.00	40.00	50.00	50.00	50.00	50.00
AREA	0.00	10.00	25.00	530.00	1100.00	1120.00	1120.00	1120.00	1120.00

FIG. 9.—Disposal Site Report

```
              ID = BAKER              BAKER DREDGING SITE

LOCATION
--------

     MAIN STEM RIVER DISTANCE....... 368303.00          NUMBER OF TRANSPORTATION LINKS..        5
     OFF MAIN STEM DISTANCE.........      0.00          MATERIAL VOLUME MULTIPLIER......     1.00

TRANSPORTATION LINK DATA
------------------------

     DISPOSAL SITE ID        MAIN STEM TRANS TYPE     OFF MAIN STEM TRANS TYPE       MAXIMUM RATE          UNIT COST

        [illegible]                NOPGOV                   NOPGOV                  21600.00                4.29
        KILLCO                     NOPGOV                   NOPGOV                  21600.00                3.25
        INDONE                     BUCK12                   NOPGOV                  21600.00               25.00
        INDTWO                     BUCK12                   NOPGOV                  21600.00               25.00
        ANTISO                     NOPGOV                   NOPGOV                  21600.00                1.63

MATERIAL VOLUMES (BEGINNING PERIOD =        1)

         1          2          3          4          5          6          7          8          9         10
  21600.00   21600.00   21600.00   21600.00   21600.00   21600.00   21600.00   21600.00   21600.00   21600.00
  21600.00   21600.00   21600.00   21600.00   21600.00   21600.00   21600.00   21600.00   21600.00   21600.00
  21600.00   21600.00   21600.00   21600.00   21600.00
```

FIG. 10.—Dredge Site Report

material are shown, and the capacity and the unit cost of excavating and transporting material to each site is tabulated. (The unit cost is determined from the appropriate unit cost versus distance function.) The estimated volumes of material to be removed each period are shown. (Note that the value shown for each period in Fig. 10 is twice the corresponding value from Table 2 because each period in the analysis corresponds to 2 yr.)

The results of optimal operation of the dredged-material disposal system are presented as a tabulation of material added to each disposal site each period and of end-of-period storage and the corresponding elevation and surface area. Fig. 11 is an example of the tabulation for one site. The results of the minimum-cost operation are summarized in Table 4. All disposal sites except the overflow sites will be filled by the end of the 50-yr model. Overflow Site 1 is used initially in the ninth 2-yr interval, indicating that system capacity falls short of demand within 18 yr of the first year. This conclusion is significant but is difficult to draw with traditional mass analysis techniques because of the complex interconnections.

Systematic Evaluation of Operation Alternatives.—Evaluation of disposal site management alternatives is accomplished by systematic application of the operation model with variation of the appropriate input parameters. For example, to evaluate the cost effectiveness of use of trenching devices that speed the drying of deposited material in the disposal sites, the volume-reduction factor, VF(*J*), and the maximum allowable volume addition per period, ADDMAX(*J*), are changed to reflect the improvement possible, and the disposal cost, CS(*J*), is altered as appropriate. The operation problem is resolved to determine the least-costly operation scheme. The cost of the trenching machinery is added to the operation cost to determine the total system cost. This total cost is compared with the total cost without the trenching devices; if the cost is less, the trenching device is cost effective.

Any management alternative can be evaluated by systematic analysis with the operation model, if the improvements attributable to that alternative can be expressed in terms of the volume-reduction factor,

DISPOSAL SITE = KILLCO KILLCONOOK DISPOSAL SITE

ACQUISITION PERIOD = 1 WET-TO-DRY RATIO = 1.50

NOTE - MATERIAL FROM DREDGE SITES IS WET.
TRANSFERRED MATERIAL IS DRY.

MATERIAL ADDED
SOLUTION FOR ITERATION = 0

SITE ID	DNEPUR HOPGOV		BULKHE HOPGOV		WEMCAS HOPGOV		TOTAL		
PERIOD	VOLUME	COST	VOLUME	COST	VOLUME	COST	VOLUME	COST	
1	2805800.	4872099.	57400.	79888.	2538800.	4343266.	5402000.	9295252.	
2	2805800.	4208793.	57400.	69011.	2538800.	3751957.	5402000.	8029761.	
3	2805800.	3635792.	57400.	59616.	2538800.	3241152.	5402000.	6936560.	
4	2805800.	3140802.	57400.	51500.	2538800.	2799889.	5402000.	5992190.	
5	2805800.	2713201.	57400.	44488.	2538800.	2418702.	5402000.	5176391.	
6	2805800.	2343816.	57400.	38431.	2538800.	2089411.	5402000.	4471658.	
7	2805800.	2024720.	57400.	33199.	2538800.	1804950.	5402000.	3862870.	
8	2805800.	1749067.	57400.	28679.	2538800.	1559218.	5402000.	3336964.	
9	2805800.	1510942.	57400.	24775.	2538800.	1346940.	5402000.	2882657.	
10	2065600.	960902.	57400.	21402.	2538800.	1163563.	4661800.	2145866.	
11	0.	0.	57400.	18488.	1725800.	683271.	1783200.	701759.	
12	0.	0.	57400.	15971.	0.	0.	57400.	15971.	
13	0.	0.	57400.	13797.	0.	0.	57400.	13797.	
14	0.	0.	57400.	11918.	0.	0.	57400.	11918.	
15	0.	0.	57400.	10296.	0.	0.	57400.	10296.	
16	0.	0.	57400.	8894.	0.	0.	57400.	8894.	FILLED
17	0.	0.	0.	0.	0.	0.	0.	0.	
18	0.	0.	0.	0.	0.	0.	0.	0.	
19	0.	0.	0.	0.	0.	0.	0.	0.	
20	0.	0.	0.	0.	0.	0.	0.	0.	
21	0.	0.	0.	0.	0.	0.	0.	0.	
22	0.	0.	0.	0.	0.	0.	0.	0.	
23	0.	0.	0.	0.	0.	0.	0.	0.	
24	0.	0.	0.	0.	0.	0.	0.	0.	
25	0.	0.	0.	0.	0.	0.	0.	0.	
TOTAL	27317800.	27160133.	918400.	530353.	27113800.	25202318.	55350000.	52892805.	

DISPOSAL SITE STATUS (DRY)
SOLUTION FOR ITERATION = 0

PERIOD	VOLUME DISPOSED	END OF PER STORAGE	DISPOSAL COST	ELEVATION	SURFACE AREA
1	3601333.	3601333.	513321.	29.19	489.24
2	3601333.	7202667.	443435.	32.54	674.81
3	3601333.	10804000.	383064.	35.31	832.71
4	3601333.	14405333.	330913.	38.08	990.62
5	3601333.	18006667.	285861.	40.55	1101.11
6	3601333.	21608000.	246943.	42.35	1104.71
7	3601333.	25209333.	213323.	44.15	1108.31
8	3601333.	28810667.	184280.	45.96	1111.91
9	3601333.	32412000.	159192.	47.76	1115.51
10	3107867.	35519867.	118676.	49.31	1118.62
11	1188800.	36708667.	39215.	49.90	1119.81
12	38267.	36746933.	1090.	49.92	1119.85
13	38267.	36785200.	942.	49.94	1119.89
14	38267.	36823467.	814.	49.96	1119.92
15	38267.	36861733.	703.	49.98	1119.96
16	38267.	36900000.	607.	50.00	1120.00
17	0.	36900000.	0.	50.00	1120.00
18	0.	36900000.	0.	50.00	1120.00
19	0.	36900000.	0.	50.00	1120.00
20	0.	36900000.	0.	50.00	1120.00
21	0.	36900000.	0.	50.00	1120.00
22	0.	36900000.	0.	50.00	1120.00
23	0.	36900000.	0.	50.00	1120.00
24	0.	36900000.	0.	50.00	1120.00
25	0.	36900000.	0.	50.00	1120.00
TOTAL	36900000.		2922378.		

FIG. 11.—Operation Report

TABLE 4.—Volume of Dredged-Material Disposed, in Million Cubic Yards before Drying

	Disposal Site							
Dredge Site (1)	Artificial Island (2)	Overflow Site 1 (3)	Overflow Site 2 (4)	National Park (5)	Killcohook (6)	Penns Neck (7)	Pedricktown North (8)	Pedricktown South (9)
Eddystone	0	0.20	0	0.05	*	*	0.20	0.17
Chester	0	0.02	0	*	*	*	0.01	0.01
Marcus Hook	0	29.25	0	8.63	*	*	27.25	27.39
Bellevue	0	0.90	0	*	*	1.00	0	0.60
Cherry Island	*	2.17	0	1.45	*	5.43	0	0
Deepwater Point	0	25.25	0	*	27.32	17.58	*	0
Bulkhead Bar	0	0.52	0	*	0.92	0	*	*
Newcastle	14.92	21.44	0	*	27.11	0	*	*
Reedy Island	0.95	0.45	0	*	0	0	*	*
Baker	0.37	0.17	0	*	0	0	*	*
Liston	7.51	3.53	0	*	0	0	*	*
Miah Maull	0.98	1.07	0	*	0	0	*	*
Brandywine	0.02	0.05	0	*	0	0	*	*
W. Horseshoe	0	0.52	0	0.05	*	*	0.36	0.36
Mifflin	0	1.35	0	0	*	*	0.94	1.08
Billingsport	0	0.10	0	0.01	*	*	0.09	0.08
Tinicum	0	0.78	0	0.09	*	*	0.69	0.60
Upper Philadelphia Harbor	0	0.13	0	0.01	*	*	0.10	0.08
Lower Philadelphia Harbor	0	3.63	0	0.36	*	*	2.90	2.18
Total	24.75	91.53	0	10.65	55.35	24.01	32.54	32.55

Note: * Indicates sites not linked (1 cu yd = 0.765 m^3).

maximum allowable addition per period, maximum storage, capacity of transfer facilities, capacity of reuse facilities, or the time at which facilities are available. Techniques that alter the volume of time distribution of dredged material that must be disposed can be analyzed in the same systematic manner because the volumes are specified by the user for each period.

Conclusions

To identify efficient dredged-material disposal management strategies, the system operation problem can be formulated and solved as a generalized minimum-cost network flow programming problem. In this formulation, the material sources and disposal sites are represented as nodes, and the transportation links and carry-over storages are represented as arcs. The network-with-gains algorithm is used for solution, thereby allowing modeling of the drying of material in the disposal sites.

The proposed disposal system operation model can be used for the evaluation of alternative management schemes by systematically varying the appropriate model parameters, re-executing the model, and comparing the net operation cost to determine the effectiveness of the scheme. In the future, this model will be linked with a branch-and-bound algorithm to identify efficient disposal system expansion schemes.

A generalized computer program to implement the proposed operations model was developed using software engineering methods. Structured analysis techniques were used to define the program requirements, and structured programming was used to transform the requirements into executable computer code.

The dredge-material disposal management model has been used successfully to evaluate the operation of the Delaware River disposal system.

Acknowledgments

The Philadelphia District, Corps of Engineers, provided the funds for development of the dredged-material disposal management model and assisted in model formulation and verification. The special assistance of Brian Heverin of that office is appreciated. The software engineering concepts were introduced at the Hydrologic Engineering Center by Rochelle Barkin, who patiently guided development of the FORTRAN program that implements the solution technique.

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Appendix II.—Notation

The following symbols are used in this paper:

$ADDMAX(J)$ = maximum allowable volume addition per period, site J;
$CF(I,J)$ = unit cost of transporting material from source I to disposal site J;
$CRT(J,J')$ = unit cost of rehandling material from disposal site J to site J';
$CRU(J)$ = unit benefit of reuse of material from site J;
$CS(J)$ = unit cost of adding material to site J;
$F(I,J,T)$ = volume of material transported from source I to site J in period T;
$FMAX(I,J)$ = capacity of transportation link between dredged-material source I and disposal site J;
$NDISP$ = number of disposal sites;
$NDRG$ = number of dredged-material sources;
$NPERS$ = number of the periods;
$RT(J,J',T)$ = volume of material transferred from site J to site J', period T;
$RTMAX(J,J')$ = capacity of transfer facilities between site J and site J';
$RU(J,T)$ = volume of material removed from site J and sold for reuse, period T;
$RUMAX(J)$ = capacity of reuse facilities, disposal site J;
$S(J,T)$ = volume stored in disposal site J, period T;
$SMAX(J)$ = capacity of disposal site J;
$V(I,T)$ = total volume of material dredged at source I during period T;
$VF(J)$ = volume reduction factor, disposal site J; and
Z = net system operating cost.

Subscripts

I = dredged-material source;
J = disposal site; and
T = time period.

APPENDIX II

D2M2 CAPACITY EXPANSION ALGORITHM

SUMMARY

The capacity expansion module of program D2M2 selects, from a user-specified set of alternatives, the least-costly plan for acquiring or leasing disposal sites to expand the capacity of a disposal system. The least-costly plan is determined by systematic enumeration and comparison of a limited number of acquisition and lease-renegotiation schedules. The cost of each is the present value of acquisition and lease-renegotiation cost plus the present value of disposal-system operation cost. The operation cost is determined by formulating a network-flow model of the alternative schedules and solving the minimum-cost flow problem to determine optimal allocation of the available space. A branch-and-bound enumeration procedure is used to select candidate expansion plans for evaluation.

BRANCH-AND-BOUND-METHODS

General Properties. - Branch-and-bound methods are intelligently structured techniques for evaluating and comparing solutions to optimization problems. With these methods, only a small fraction of all possible solutions actually are enumerated. The remaining solutions are eliminated from consideration through establishment of progressively stricter bounds on the cost or benefit of solutions (the objective function). These bounds aid in identification of inferior solutions without requiring extensive computation to evalute those solutions.

Branch-and-bound techniques consist of two basic operations: (1) dividing the set of possible solutions into subsets (branching), and (2) establishing bounds on the value of the objective function, so inferior solutions can be eliminated (bounding). The methods involve recursive application of these operations, with specific rules for the operations depending on the characteristics of the problem.

References. - The general characteristics of branch-and-bound methods and applications of the methods have been presented in the management science and operations research literature. Lawler and Wood (6) present a survey of the essential features of branch-and-bound methods for constrained optimization problems and describe application to integer and nonlinear programming problems, to the traveling-salesman problem, to the quadratic assignment problem, and to non-mathematical programming problems. Mitten (9) describes the general properties of branch-and-bound methods and presents, in general terms, the conditions for branching and for bounding the results of optimization problems. Garfinkel and Nemhauser (5) describe branch-and-bound methods applicable to integer programming problems.

Branch-and-bound methods have been applied in resource planning to problems of sizing, selecting, sequencing, and scheduling projects. Marks and Liebman (8) suggest using a branch-and-bound procedure for locating solid-waste management facilities. Brill and Nakamura (3) and Nakamura and Brill (11) propose application of a branch-and-bound method for generating systematically alternative plans for regional wastewater treatment systems and for evaluating these alternative plans. Application of branch-and-bound

methods for selection of the optimal combination of discrete alternatives is addressed by Efroymson and Ray (4), by Morin (10) and by Ball, Bialas, and Loucks (1).

The branch-and-bound procedure incorporated in program D2M2 is an adaptation of the procedure suggested by Lesso, Himmelblau, Jensen, and Shanmugham (7) and the procedure suggested by Bickel (2). These references provide a mathematically vigorous explanation of the procedure.

CAPACITY EXPANSION ALGORITHM

The branch-and-bound algorithm of program D2M2 identifies the least-costly capacity expansion plan by (1) defining, for each site, a time window during which the site may be acquired, (2) partitioning this time window repeatedly, (3) determining a lower bound on the cost if the sites are acquired within the partitions, (4) analyzing the utilization of each disposal site within the defined partitions, (5) estimating the cost of alternative partitions for each site, (6) reducing the partition for the site which will yield the greatest reduction in overall cost, and (6) repeating the process until the partition for each site is reduced to a single period or until an iteration limit is exceeded.

Branching. - The branch-and-bound procedure partitions the set of all possible capacity expansion plans into progressively smaller subsets and compares the cost of these subsets. The partitioning, or bounding, is accomplished using an acquisition time window. For each expansion site, the program user defines the earliest and latest acceptable acquisition periods. The many alternative acquisition options represented by this acquisition time window are evaluated by partitioning repeatedly the initial window into small candidate segments and evaluating the cost of each. Each of these segments represents a capacity-expansion plan with site acquisition sometime between two periods within the user-specified time window The partitioning continues until the candidate segments are reduced to a single period; this defines the acquisition period.

Fig. 3 shows how the branch-and-bound algorithm might partition a user-specified acquisition time window for evaluation. Site acquisition is possible between 2000 and 2050. For analysis of system operation with the site acquired after 2000 and before 2050, a partition is made yielding two candidates: acquisition after 2010 and in or before 2050. Analysis of these options leads to partitioning of the latter candidate. (The option of acquiring the site between 2000 and 2010 will be evaluated later.) The partition yields two candidate plans: acquisition between 2010 and 2020 or acquisition between 2020 and 2050. Following analysis of system operation, the option of acquiring the site between 2011 and 2020 is partitioned. The resulting candidates specify acquisition between 2011 and 2015 or between 2016 and 2020. The earlier acquisition promises to provide greater cost reduction, so it is analyzed, and an additional partition is made. In this partition, the site may be acquired in 2011 or in or after 2012 and in or before 2015. If the first option is feasible a, solution to the capacity expansion problem has been found.

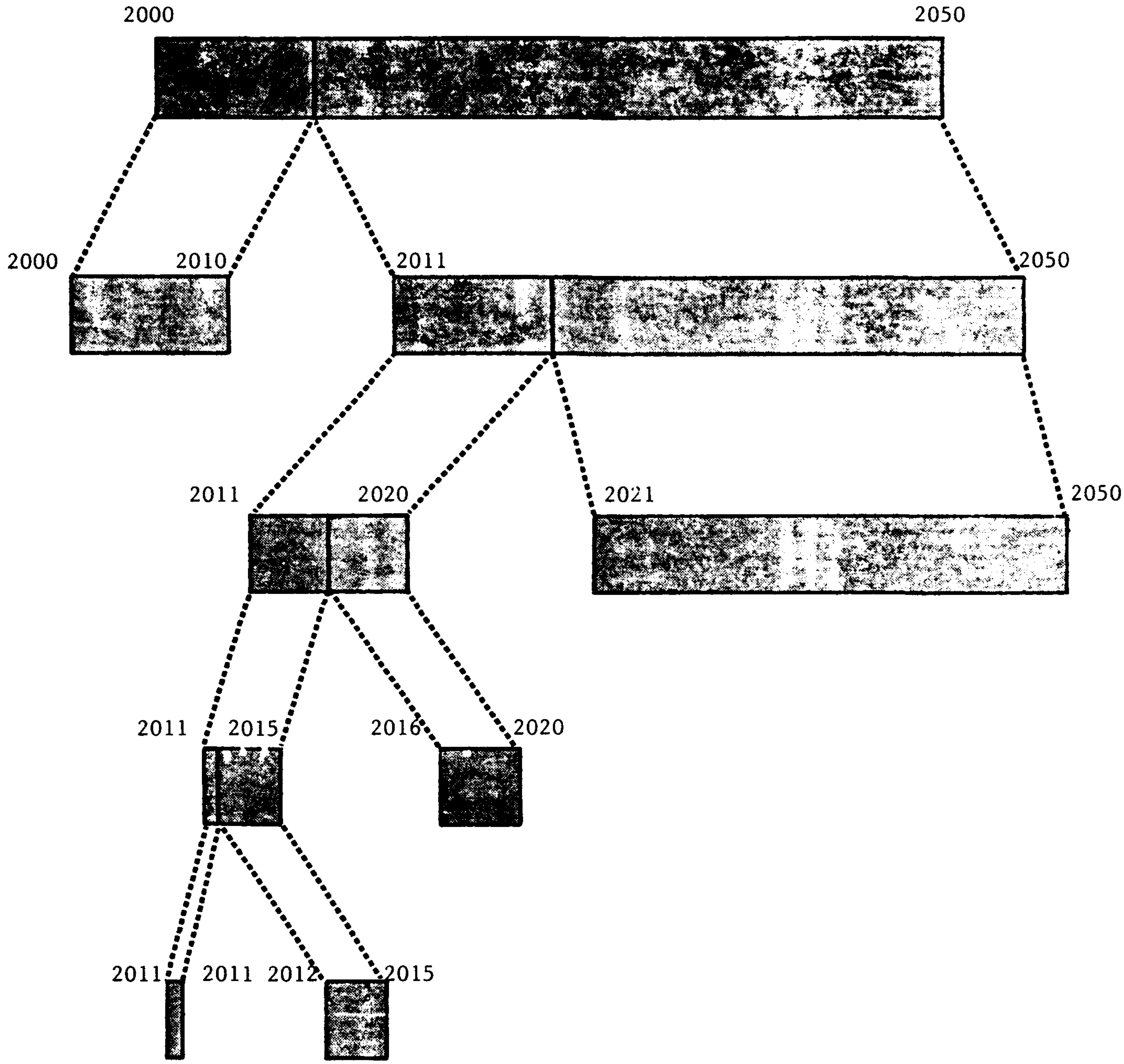

FIG. 3. - Acquisition Time Window Partitioning Example

If several capacity expansion sites are available, the capacity expansion plans are partitioned based on combinations of the acquisition periods. For example, the program user may specify that site A can be acquired between 2000 and 2050, and site B can be acquired between 1990 and 2010. The solution can be partitioned into candidates in which A is acquired between 2000 and 2025 with B acquired between 1990 and 2010 and candidates in which A is acquired between 2026 and 2050 with B acquired between 1990 and 2010. The first solution can be partitioned further into solutions in which A is acquired between 2000 and 2025 with B acquired between 1990 and 1998 and solutions with the same acquisition window for A but with B acquired between 1999 and 2010. This partitioning continues until a single acquisition period is found for each site.

Evaluating Cost. - The true cost of each capacity-expansion plan is the present value of acquistion and lease-renegotiation cost plus the present value of disposal-system operation cost. If the acquisition period for each site is known, this cost can be computed by discounting appropriately the acquisition cost from the period of acquisition, adding the discounted OMR cost, and adding the discounted operation cost. The discounted operation cost is computed by formulating a network model and solving to define the least-costly operation. During the search for the optimal capacity-expansion plan with partitions of the acquisition time window, the period of acquisition for any candidate capacity-expansion plan is known only to fall between the earliest and latest periods which define the partition. Consequently the acquisition and lease renegotiation cost cannot be computed exactly. For each disposal site it is estimated as a function of disposal-site utilization as follows:

1. The annual equivalent of the acquisition cost is determined using a user-specified amortization period. The annual OMR cost is added.

2. The resulting cost is divided by the capacity of the site, yielding a unit cost approximation.

3. This unit cost is added to the user-specified cost of disposing material in the site. The present value of the unit cost is determined for each period between the earliest and latest defined by the partition. The resulting unit costs are assigned to the network model arcs representing storage in the disposal site.

The total cost computed using the estimate described always under-estimates or is exactly equal to the true cost. Lesso, Himmelblau, Jensen, and Shanmugham (7) prove this. This fact is critical for eliminating inferior solutions without explicitly evaluating the solutions. If two alternative expansion plans are compared, the plan with the greatest cost is inferior, regardless of the size of the partition. Even if another, smaller partition of the inferior plan is defined, the cost will not decrease. Thus all solutions in which the site is acquired between the periods defining the partition can be eliminated from further consideration. Any effort to increase the earliest period or to decrease the latest period is wasted.

Bounding. - The branch-and-bound procedure estimates the cost of each candidate solution and compares the cost with an upper bound on the total cost. This upper bound is the value of the best solution found in the iterative procedure and is updated when better solutions are found. If the

value of any candidate solution exceeds the upper bound, the candidate may be eliminated from further consideration. Furthermore, because the cost of the candidate represents a lower bound for solutions that might result from additional partitioning, all additional partitions can be eliminated also.

Estimating Cost Reduction. - Selection of the partition of the acquisition time window for further investigation is accomplished by estimating possible cost reduction. Each capacity expansion site is considered in turn, and the cost of the unused capacity is estimated. Later acquisition of a site should decrease this cost, but it also renders the project unusable in earlier periods, so additional cost is incurred then. The algorithm computes the sum of the possible cost decrease and the cost increase due to modification of the acquisition period. The site that promises the greatest cost decrease is selected for further partitioning of the solution. The partition is made in the period which yields this decrease.

Reiterating. - When a site is selected for partitioning and a period is selected in which the partitioning is to occur, the latest or earliest period for acquisition of the site is redefined to equal the selected period. Thus a new partition of the acquisition time window is defined for that site; the partition is smaller than the originally-defined window. The costs are then re-estimated and the evaluation is repeated. The procedure terminates when the earliest and latest acquisition periods coincide for each project or when a user-specified iteration limit is reached.

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APPENDIX III

D2M2 EXAMPLES

Program D2M2 provides the capability to model a variety of disposal systems and to simulate a variety of system operation criteria. This appendix includes five examples which illustrate program capabilities. Each example includes a description of the problem, with input to and output from program D2M2. Key items of the input and output are numbered for convenience of explanation.

Example one illustrates application of D2M2 to analyze the continuous operation of an existing disposal system. In example two, the restart capability of the program is used to analyze operation for two successive 25-year planning periods. Example three is a modification of example one, with provisions for "resting" the Edgewood site for two periods after each three periods of availability. Example four illustrates simulation specification of a portion of the operation policy. The capacity expansion capability of the program is illustrated by example five.

EXAMPLE ONE: ANALYSIS OF CONTINUOUS OPERATION

This example illustrates application of program D2M2 to determine the status of and operation cost of a dredged-material disposal system if the least-costly operation policy is followed for 50 periods, each of which is one year in duration. The system consists of two dredging sites from which material may be transported to four disposal sites, as illustrated by Fig. 4. Analysis begins in 1981. The ocean disposal site and the Williamson Harbor and Edgewood sites are available in 1981 and remain available throughout the 50-year analysis period. The lease on the Edgewood site is to be renegotiated in 1999 at a cost of $10,000. The Williamson Harbor South disposal site is not available until 1987, when it is acquired at a cost of $1,725,000. This cost is amortized with 7-5/8% per period discount rate. The present value of all costs is determined using the same discount rate. Two dredging and transporting techniques are employed: a 16-inch pipeline dredge and a government-owned hopper dredge. The unit cost of dredging and transporting the material is a function of the distance from the dredging site to the disposal site.

Reproductions of selected portions of the D2M2 output are included herein. Key items are numbered for convenience of explanation.

The program banner page (item 1) identifies the version of the program and the latest revision of the users manual. The date and time of program execution are also shown.

Item 2 is a list of all user-provided input, exactly as read by the program. The cards are numbered for subsequent reference. The input for this example includes three title cards (cards 1, 2, and 3), and a J1 card (card 4) for system dimension specification and job control. The values on the J1 card indicate that 50 periods will be analyzed, beginning in 1981 (fields 1 and 2). Each period in this case is one year, but the calculations performed do not require or assume this duration. Fields 4, 5, and 6 of the J1 card define the number of disposal sites, number of dredge sites, and number of dredged-material transportation methods. The value in field 9

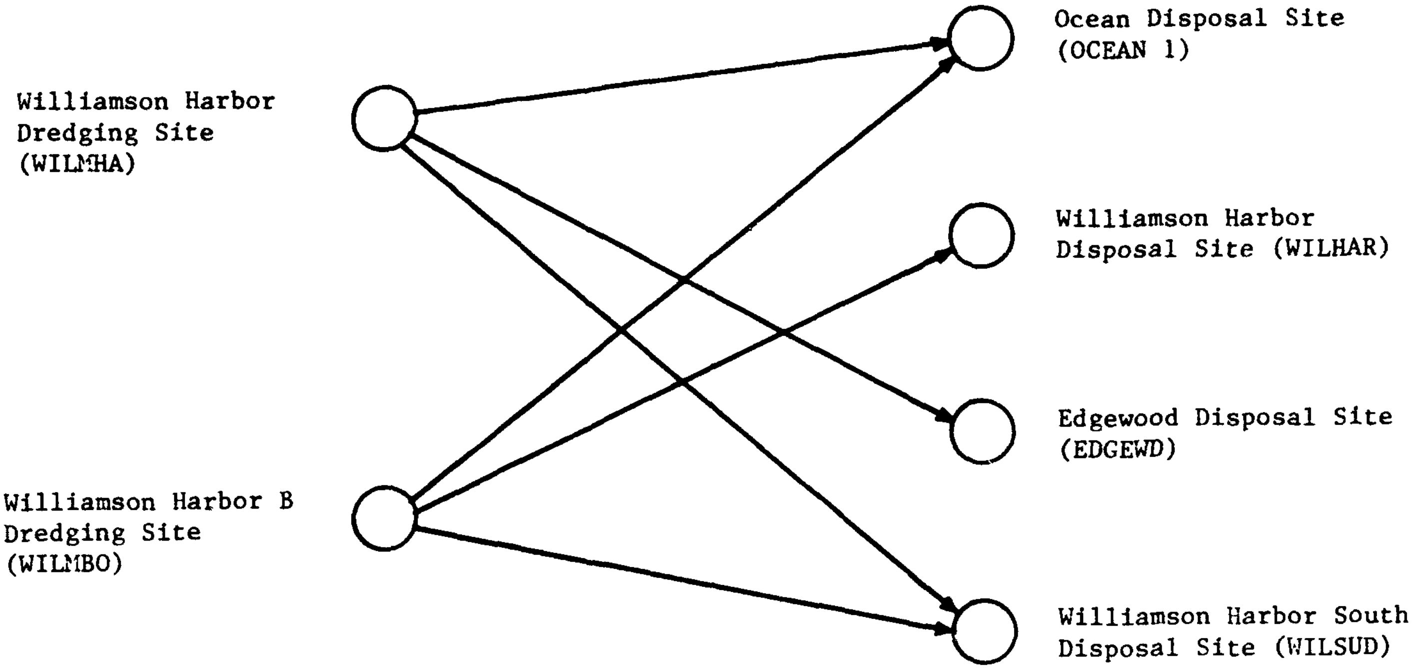

FIG. 4. - Disposal System for Example One

specifies 15 periods for amortization of site acquisition costs; the discount rate of 7-5/8 percent per period is specified in field 3. Identification of the amortization period is required to allow proper computation of the present value of acquisition costs for comparison of alternative schemes. A set of cards TI, TD, and TC cards (cards 5-10) is included for each of the two dredging techniques. These cards identify the dredging technique and describe the distance-cost function for each. The values of unit cost as a function of distance are used with computed distance to estimate appropriate unit costs between interconnected sites. Linear interpolation is used, so the values specified must be selected accordingly. Cards 11-16 define the characteristics of the Ocean disposal site, cards 17-22 define the characteristics of the Williamson Harbor South disposal area, cards 23-28 describe the Williamson Harbor disposal area, and cards 29-34 describe the Edgewood site. Fields 1 and 2 of the SL cards define the location of each site; the program uses these to compute distances. The off-river distance for the ocean site (field 2 of card 12) is specified as an arbitrary, large value to yield a high cost, thus discouraging ocean disposal. The acquisition status of each site is defined by the value in field 1 of the SX cards (cards 13, 19, 25, and 31). The ocean, Williamson Harbor, and Edgewood sites are added to the system in 1981, as specified by the value in field 2 of the SX cards. Acquisition costs for these sites are ignored in this analysis, so these are omitted from the SX cards. The ocean, and Williamson Harbor sites are available throughout the analysis, as specified in field 4 of the SX cards. In the case of the Edgewood site, the lease is to be renegotiated in 1999, as specified by the value in field 4 of card 31. That site is then available throughout the remainder of the analysis. The Williamson Harbor South site is added to the system in 1987 (field 2 of card 19) and is available throughout the analysis. The Williamson Harbor dredging site is described by DI, DL, and DT cards (cards 35-39), and the volume of material dredged in each period is specified on DV cards (cards 40-45). For this example, the total volume is specified for each period, so six DV cards are required with nine values specified on each. Cards 46-56 describe the Williamson Harbor B site and define the volume dredged each period.

Each input error detected by the program is identified (item 3). The sequence number of the card and the variable which is specified incorrectly are shown. If a default value is used rather than the specified value, the default value is shown.

The basic data summary (item 4) shows the values specified by the user on the J1 card. Item 5 is the summary of dredge and transportation data.

The disposal site input reports summarize the data for each disposal site in turn. The report for the Williamson Harbor South disposal area comprises items 6-17. Similar reports are printed for each site but are not shown here. Item 6 is the specified location of the disposal site in terms of main-stem river distance and off-main-stem distance. Any origin for measurement may be used, but all river distances must be specified relative to the same origin. The off-main-stem distance may be specified as a positive or negative distance, depending on the location to the right or left of the main river. The off-river transportation type also is shown. If this field is blank, the transportation type is assumed to be the same as the transportation type used on the main-stem. Item 7 is the disposal site storage data, including the initial volume of material in the containment site, the wet-to-dry ratio (volume of wet material divided by volume of

material after drying), the maximum allowable rate of addition of wet material, and the unit cost for addition of material to the disposal site. For the Williamson Harbor South Disposal area, no maximum allowable rate is specified (field 6 of card 19), so the site capacity is used as the default value. The site acquisition cost (in 1981 dollars), acquisition date, and the expansion indicator (field 1 of card 19) are shown (item 8). The present value of the acquisition cost is determined and is added to the system operation cost. If the site is leased and a lease-termination date is specified, this is shown (item 9). Lease renegotiation costs are also shown here. The present value of the renegotiation costs is determined and is added to the sum of acquisition cost and operation cost. Data on reuse of dried material from the disposal site are summarized (item 10), and transfer data are reported if provided (item 11). No transfer of material from this site is possible, so no data are shown here. If transfer is possible, the potential ultimate disposal sites and the transportation techniques are identified. Finally the capacity-elevation-area function for the disposal site is shown (item 12). Linear interpolation is used with these values, so they should be specified accordingly.

The dredge-site input report for the Williamson Harbor dredging site (items 13, 14, and 15) shows the volumes of material dredged, by period, and the techniques available to accomplish the dredging and transporting of material to the disposal sites. A similar report is prepared for each site, but these are not shown here. The dredging site location (item 13) is specified in terms of main-stem river distance and off-main-stem distance, using a constant origin for main-stem locations and positive or negative distances for off-main-stem distances. The material volume multiplier is a convenience to allow scaling of all specified volumes for this disposal site prior to analysis of system operation. If desired, this may be used to account for the difference of volume in situ and volume to be transported. The transportation link data summary (item 14) identifies disposal sites in which material from this dredging site may be disposed and the techniques for and unit cost of moving the material to the sites. Finally the material volumes are tabulated (item 15); these are the user-supplied values, scaled by the volume multiplier.

The volume summary report (item 16) shows the total volume by period, before drying and consolidating, that must be disposed within the specified system. The dimensions of the resulting network-flow programming model are shown (item 17).

The capacity expansion iteration log serves as a cost summary in this application of D2M2. Only a single execution on the model is required; this is shown as iteration 0 (item 18). The disposal sites are identified and pertinent acquisition and lease dates are shown. The sum of present value of site acquisition, lease renegotiation, and operation, maintenance, and replacement (OMR) costs for all sites is computed and shown (item 19). The minimum-cost present value of system operation cost is shown, as determined by solution of the network-flow programming problem (item 20). This cost represents the cost of material transportation and disposal, less the revenue from reuse. The total net cost (item 21) is the total of acquisition, lease renegotiation, OMR, and operation costs for all sites for the period of analysis.

The results of optimal operation of the dredged-material disposal system are presented as reports of the status of and changes to each disposal site. These reports include a tabulation of material added to the disposal site, either from dredging sites or from other disposal sites, a tabulation of material removed from the site for transfer or reuse, and a tabulation of the containment site storage, elevation, and surface area. An example, the report for the Williamson Harbor South site, comprises items 22-25. Similar reports are presented for all sites, but are not included here.

The Williamson Harbor South disposal site may be used for containment of material from the Williamson Harbor dredging site and from the Williamson Harbor B dredging site. The volume of material transported from each is shown and the discounted transportation cost is tabulated (item 22). The total for all dredging sites is shown (item 23), and the total for all periods is computed and tabulated (Item 25). If the site fills, this is indicated (item 24). The disposal-site status report shows for each period the total volume of consolidated material added to the site (item 26), the resulting volume of material stored at the end of each period (item 27), and the disposal cost (item 32). The elevation (item 29) and surface area (item 30) corresponding to each storage are determined by reference to the user-provided capacity-elevation-area function. The total volume of consolidated material added and the cost of the addition are presented (item 31).

System operation for the entire period of analysis is summarized in the dredged-material source/disposal site report (item 32). Each dredged-material source and disposal site is shown in this matrix. The total volume moved from each source to each disposal site is shown, and the first and last periods of disposal site utilization are shown.

Item 33 is a graphic summary of disposal site use. Each period that any material is deposited in a site is indicated by an "X" in the appropriate column.

```
*******************************************************
* DREDGE DISPOSAL MANAGEMENT MODEL                    *
* USERS MANUAL UPDATED JULY 1984                      *
* UPDATED JULY      1984 VERSION 6.0                  *
*                                                     *
*  RUN DATE  2 JUL 84  TIME  07:26:13                 *
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****************************************
*  U.S. ARMY CORPS OF ENGINEERS        *
*  THE HYDROLOGIC ENGINEERING CENTER   *
*  609 SECOND STREET, SUITE B          *
*  DAVIS, CALIFORNIA  95616            *
*  (916) 440-2105 (FTS) 448-2105       *
****************************************
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1

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DDDDDD    22222   M     M   22222
D     D  2     2  MM   MM  2     2
D     D        2  M M M M        2
D     D    2222   M  M  M    2222
D     D   2       M     M   2
D     D  2        M     M  2
DDDDDD   2222222  M     M  2222222
```

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** LIST OF RECORDS READ BY READIN **
RECORD
 ORDER          1         2         3         4         5         6         7         8
NUMBER 12345678901234567890123456789012345678901234567890123456789012345678901234567890

     1 T1      EXAMPLE ONE - D2M2 USERS MANUAL
     2 T2      ANALYSIS OF CONTINUOUS OPERATION
     3 T3
     4 J1    50    1981   7.625       4       2       2                      15
     5 TIHOPGOV  GOVERNMENT HOPPER DREDGE
     6 TD  5280   52800   79200  105600  158400  211200  264000  316800  422400  528000
     7 TC  1.40    3.00    3.90    4.75    6.60    8.40   10.20   11.95   15.60   19.30
     8 TI16PIPM  16-INCH PIPELINE DREDGE
     9 TD     0    1000    3000    6950    7000   13950   14000   20950   21000   28000
    10 TC     0    0.75    0.90    1.50    2.00    2.40    2.75    3.25    3.60    4.70
    11 SIOCEAN1  OCEAN SITE ONE
    12 SL  7000  500000
    13 SX
    14 SSOCEAN1       099999999
    15 SEOCEAN1       0      99
    16 SAOCEAN1       0     626
    17 SIWILSUD  WILLIAMSON HARBOR SOUTH DISPOSAL AREA
    18 SL  5500    2500                    2.0             0.75
    19 SX     0    1987                                                         1725000
    20 SSWILSUD       0 5565000 895200011533000
    21 SEWILSUD      -3      12      22      30
    22 SAWILSUD     230     230     210     200
    23 SIWILHAR  WILLIAMSON HARBOR DISPOSAL AREA
    24 SL  1000       0                    2.0             0.60
    25 SX
    26 SSWILHAR       0 1075000 1575000 2875000 5770000
    27 SEWILHAR      28      32      38      40      50
    28 SAWILHAR       0     165     173     176     174
    29 SIEDGEWD  EDGEWOOD DISPOSAL AREA
    30 SL  4000                            2.0             0.60
    31 SX     1                    1999   10000
    32 SSEDGEWD       0  130000  930000 1130000 3530000
    33 SEEDGEWD       0      35      40      41      50
    34 SAEDGEWD       0      62     210     212     210
    35 DIWILMHA  WILLIAMSON HARBOR DREDGING SITE
    36 DL  3000               3
    37 DTEDGEWD  16PIPM
    38 DTOCEAN1  HOPGOV
    39 DTWILSUD  16PIPM
    40 DV      1100000 1100000  550000       0  550000 1100000  550000       0 1100000
    41 DV      1100000       0       0 1100000 1100000       0       0 1100000 1100000
    42 DV            0       0 1100000 1100000       0       0  550000  550000  550000
    43 DV       550000  550000  550000  550000  550000  550000  550000  550000  550000
    44 DV       550000  550000  550000  550000  550000  550000  550000  550000  550000
    45 DV       550000  550000  550000  550000  550000
    46 DIWILMBO  WILLIAMSON HARBOR B DREDGING SITE
    47 DL  3000               3
    48 DTWILSUD  16PIPM
    49 DTWILHAR  16PIPM
    50 DTOCEAN1  HOPGOV
    51 DV            0       0  550000 1100000  550000       0  550000 1100000       0
    52 DV            0 1100000 1100000       0       0 1100000 1100000       0       0
    53 DV      1100000 1100000       0       0 1100000 1100000  550000  550000  550000
    54 DV       550000  550000  550000  550000  550000  550000  550000  550000  550000
    55 DV       550000  550000  550000  550000  550000  550000  550000  550000  550000
    56 DV       550000  550000  550000  550000  550000

READIN --     56 RECORDS WRITTEN TO LOGICAL FILE 12
```

2

```
                         EXAMPLE ONE - D2M2 USERS MANUAL
                         ANALYSIS OF CONTINUOUS OPERATION

*******************
***** WARNING *****      THE VALUE OF ITMAX (        0) ON THE J1 CARD IS INVALID
                         ITMAX SET EQUAL TO DEFAULT (       25 )
*******************

*******************
***** WARNING *****      THE VALUE OF WDRAT (     0.00) ON THE SL CARD NO.  12 IS INVALID
                         WDRAT SET EQUAL TO DEFAULT ( 1.0)
*******************

*******************
***** WARNING *****      THE VALUE OF VMULT (     0.00) ON THE DL CARD NO.  36 IS INVALID
                         VMULT SET EQUAL TO DEFAULT ( 1.0)
*******************

*******************
***** WARNING *****      THE VALUE OF VMULT (     0.00) ON THE DL CARD NO.  47 IS INVALID
                         VMULT SET EQUAL TO DEFAULT ( 1.0)
*******************
```

3

EXAMPLE ONE - D2M2 USERS MANUAL
ANALYSIS OF CONTINUOUS OPERATION

BASIC DATA

NUMBER OF PERIODS OF ANALYSIS..	50	NUMBER OF DISPOSAL SITES........	4	4
FIRST PERIOD..................	1981	NUMBER OF DREDGE SITES..........	2	
DISCOUNT RATE PER PERIOD.......	7.63	NUMBER OF TRANSPORTATION TYPES..	2	
MAXIMUM NUMBER OF ITERATIONS...	25	OUTPUT CONTROL VARIABLE.........	0	
NUMBER OF AMORTIZATION PERIODS.	15	NUMBER OF PERIODS TO RESTART....	0	

TRANSPORTATION DATA

ID = HOPGOV GOVERNMENT HOPPER DREDGE

	1	2	3	4	5	6	7	8	9	10	
DISTANCE	5280.00	52800.00	79200.00	105600.00	158400.00	211200.00	264000.00	316800.00	422400.00	528000.00	5
UNIT COST	1.40	3.00	3.90	4.75	6.60	8.40	10.20	11.95	15.60	19.30	

ID = 16PIPM 16-INCH PIPELINE DREDGE

	1	2	3	4	5	6	7	8	9	10
DISTANCE	0.00	1000.00	3000.00	6950.00	7000.00	13950.00	14000.00	20950.00	21000.00	28000.00
UNIT COST	0.00	0.75	0.90	1.50	2.00	2.40	2.75	3.25	3.60	4.70

EXAMPLE ONE - D2M2 USERS MANUAL
ANALYSIS OF CONTINUOUS OPERATION

DISPOSAL SITE INPUT REPORT

ID = WILSUD WILLIAMSON HARBOR SOUTH DISPOSAL AREA

LOCATION

(6)

MAIN STEM RIVER DISTANCE.......	5500.00
OFF MAIN STEM DISTANCE.........	2500.00
OFF RIVER TRANSPORTATION TYPE..	

STORAGE DATA

(7)

INITIAL STORAGE.............	0.00
WET-TO-DRY RATIO............	2.00
MAXIMUM ADDITION/PERIOD.....	11533000.
DISPOSAL COST...............	0.75

SITE ACQUISITION DATA

(8)

ACQUISITION COST...............	1725000.
EXPANSION INDICATOR............	0
EARLIEST ACQUISITION DATE......	1987
LATEST ACQUISITION DATE......	1987
NO. OF PERIODS BEFORE RESTING..	0
NO. OF RESTING PERIODS.........	0

LEASE DATA

(9)

END OF LEASE DATE...........	2031
RENEGOTIATION COST..........	0.

REUSE DATA

(10)

FIRST PERIOD AVAILABLE.........	0
MAXIMUM ALLOWABLE RATE.........	0.00
UNIT BENEFIT...................	0.00

FIXED ANNUAL O,M+R COSTS......... 0.

TRANSFER DATA

NUMBER OF TRANSFER SITES = 0

(11)

(12)

	1	2	3	4	5	6	7	8	9
CAPACITY	0.	5565000.	8952000.	11533000.	11533000.	11533000.	11533000.	11533000.	11533000.
ELEVATION	-3.00	12.00	22.00	30.00	30.00	30.00	30.00	30.00	30.00
AREA	230.00	230.00	210.00	200.00	200.00	200.00	200.00	200.00	200.00

EXAMPLE ONE - D2M2 USERS MANUAL
ANALYSIS OF CONTINUOUS OPERATION

DREDGE SITE INPUT REPORT

ID = WILMHA WILLIAMSON HARBOR DREDGING SITE

LOCATION

MAIN STEM RIVER DISTANCE.......	3000.00	NUMBER OF TRANSPORTATION LINKS..	3	13
OFF MAIN STEM DISTANCE.........	0.00	MATERIAL VOLUME MULTIPLIER......	1.00	

TRANSPORTATION LINK DATA

DISPOSAL SITE ID	MAIN STEM TRANS TYPE	OFF MAIN STEM TRANS TYPE	MAXIMUM RATE	UNIT COST
EDGEWD	16PIPM		0.00	0.75
OCEAN1	HOPGOV		0.00	18.46
WILSUD	16PIPM		0.00	1.20

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MATERIAL VOLUMES (BEGINNING PERIOD = 1981)

1	2	3	4	5	6	7	8	9	10
1100000.00	1100000.00	550000.00	0.00	550000.00	1100000.00	550000.00	0.00	1100000.00	1100000.00
0.00	0.00	1100000.00	1100000.00	0.00	0.00	1100000.00	1100000.00	0.00	0.00
1100000.00	1100000.00	0.00	0.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00
550000.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00
550000.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00	550000.00

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EXAMPLE ONE - D2M2 USERS MANUAL
ANALYSIS OF CONTINUOUS OPERATION

VOLUME SUMMARY REPORT

16

PERIOD	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
VOLUME	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.
PERIOD	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
VOLUME	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.
PERIOD	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
VOLUME	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.
PERIOD	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
VOLUME	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.
PERIOD	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
VOLUME	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.	1100000.

NETWORK CONTAINS 490 NODES, 780 ARCS, OUTFLO = 55000000.

17

EXAMPLE ONE – D2M2 USERS MANUAL
ANALYSIS OF CONTINUOUS OPERATION

CAPACITY EXPANSION ITERATION LOG

ITER	SITE ID	SITE ACQ. PERIOD	LEASE TERM. PER.	SITE TERM. PER.	PRESENT VALUE ACQ.+RENEG.+OMR COST	PRESENT VALUE OPERATION COST	TOTAL NET COST
0	OCEAN1	1981	2031	2031			
	WILSUD	1987	2031	2031			
	WILHAR	1981	2031	2031			
	EDGEWD	1981	1999	2031	1112443.	30585697.	31698139.

18 19 20 21

EXAMPLE ONE - D2M2 USERS MANUAL
ANALYSIS OF CONTINUOUS OPERATION

DISPOSAL SITE = WILSUD WILLIAMSON HARBOR SOUTH DISPOSAL AREA

ACQUISITION PERIOD = 1987 WET-TO-DRY RATIO = 2.00

NOTE - MATERIAL FROM DREDGE SITES IS WET.
TRANSFERRED MATERIAL IS DRY.

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MATERIAL ADDED
SOLUTION FOR ITERATION = 0

23

SITE ID	WILMHA 16PIPM		WILMBO 16PIPM				TOTAL		
PERIOD	VOLUME	COST	VOLUME	COST	VOLUME	COST	VOLUME	COST	
1981	0.	0.	0.	0.	0.	0.	0.	0.	
1982	0.	0.	0.	0.	0.	0.	0.	0.	
1983	0.	0.	0.	0.	0.	0.	0.	0.	
1984	0.	0.	0.	0.	0.	0.	0.	0.	
1985	0.	0.	0.	0.	0.	0.	0.	0.	
1986	0.	0.	0.	0.	0.	0.	0.	0.	
1987	0.	0.	0.	0.	0.	0.	0.	0.	
1988	0.	0.	0.	0.	0.	0.	0.	0.	
1989	0.	0.	0.	0.	0.	0.	0.	0.	
1990	90000.	51959.	0.	0.	0.	0.	90000.	51959.	
1991	0.	0.	0.	0.	0.	0.	0.	0.	
1992	0.	0.	0.	0.	0.	0.	0.	0.	
1993	1100000.	509419.	0.	0.	0.	0.	1100000.	509419.	
1994	1100000.	473328.	0.	0.	0.	0.	1100000.	473328.	
1995	0.	0.	0.	0.	0.	0.	0.	0.	
1996	0.	0.	0.	0.	0.	0.	0.	0.	
1997	1100000.	379684.	0.	0.	0.	0.	1100000.	379684.	
1998	1100000.	352784.	0.	0.	0.	0.	1100000.	352784.	
1999	0.	0.	0.	0.	0.	0.	0.	0.	
2000	0.	0.	0.	0.	0.	0.	0.	0.	
2001	1100000.	282989.	0.	0.	0.	0.	1100000.	282989.	
2002	1100000.	262940.	0.	0.	0.	0.	1100000.	262940.	
2003	0.	0.	10000.	2221.	0.	0.	10000.	2221.	
2004	0.	0.	1100000.	227002.	0.	0.	1100000.	227002.	
2005	550000.	105460.	550000.	105460.	0.	0.	1100000.	210920.	
2006	550000.	97988.	550000.	97988.	0.	0.	1100000.	195976.	
2007	550000.	91046.	550000.	91046.	0.	0.	1100000.	182092.	
2008	550000.	84596.	550000.	84596.	0.	0.	1100000.	169191.	
2009	550000.	78602.	550000.	78602.	0.	0.	1100000.	157204.	
2010	550000.	73033.	550000.	73033.	0.	0.	1100000.	146067.	
2011	550000.	67859.	550000.	67859.	0.	0.	1100000.	135718.	
2012	550000.	63051.	550000.	63051.	0.	0.	1100000.	126103.	
2013	550000.	58584.	550000.	58584.	0.	0.	1100000.	117169.	
2014	550000.	54434.	550000.	54434.	0.	0.	1100000.	108868.	
2015	550000.	50577.	550000.	50577.	0.	0.	1100000.	101155.	
2016	550000.	46994.	550000.	46994.	0.	0.	1100000.	93988.	24
2017	550000.	43665.	550000.	43665.	0.	0.	1100000.	87329.	
2018	550000.	40571.	416000.	30686.	0.	0.	966000.	71257.	FILLED
2019	0.	0.	0.	0.	0.	0.	0.	0.	
2020	0.	0.	0.	0.	0.	0.	0.	0.	
2021	0.	0.	0.	0.	0.	0.	0.	0.	
2022	0.	0.	0.	0.	0.	0.	0.	0.	
2023	0.	0.	0.	0.	0.	0.	0.	0.	
2024	0.	0.	0.	0.	0.	0.	0.	0.	
2025	0.	0.	0.	0.	0.	0.	0.	0.	
2026	0.	0.	0.	0.	0.	0.	0.	0.	
2027	0.	0.	0.	0.	0.	0.	0.	0.	
2028	0.	0.	0.	0.	0.	0.	0.	0.	
2029	0.	0.	0.	0.	0.	0.	0.	0.	
2030	0.	0.	0.	0.	0.	0.	0.	0.	
TOTAL	14390000.	3269563.	8676000.	1175799.	0.	0.	23066000.	4445363.	25

26 27 DISPOSAL SITE STATUS (DRY)
SOLUTION FOR ITERATION = 0 30

PERIOD	VOLUME DISPOSED	END OF PER STORAGE	DISPOSAL COST 28	ELEVATION 29	SURFACE AREA
1981	0.	0.	0.	-3.00	230.00
1982	0.	0.	0.	-3.00	230.00
1983	0.	0.	0.	-3.00	230.00
1984	0.	0.	0.	-3.00	230.00
1985	0.	0.	0.	-3.00	230.00
1986	0.	0.	0.	-3.00	230.00
1987	0.	0.	0.	-3.00	230.00
1988	0.	0.	0.	-3.00	230.00
1989	0.	0.	0.	-3.00	230.00
1990	45000.	45000.	32372.	-2.88	230.00
1991	0.	45000.	0.	-2.88	230.00
1992	0.	45000.	0.	-2.88	230.00
1993	550000.	595000.	317382.	-1.40	230.00
1994	550000.	1145000.	294897.	0.09	230.00
1995	0.	1145000.	0.	0.09	230.00
1996	0.	1145000.	0.	0.09	230.00
1997	550000.	1695000.	236554.	1.57	230.00
1998	550000.	2245000.	219795.	3.05	230.00
1999	0.	2245000.	0.	3.05	230.00
2000	0.	2245000.	0.	3.05	230.00
2001	550000.	2795000.	176310.	4.53	230.00
2002	550000.	3345000.	163819.	6.02	230.00
2003	5000.	3350000.	1384.	6.03	230.00
2004	550000.	3900000.	141429.	7.51	230.00
2005	550000.	4450000.	131409.	8.99	230.00
2006	550000.	5000000.	122099.	10.48	230.00
2007	550000.	5550000.	113448.	11.96	230.00
2008	550000.	6100000.	105411.	13.58	226.84
2009	550000.	6650000.	97943.	15.20	223.59
2010	550000.	7200000.	91004.	16.83	220.35
2011	550000.	7750000.	84556.	18.45	217.10
2012	550000.	8300000.	78566.	20.07	213.85
2013	550000.	8850000.	72999.	21.70	210.60
2014	550000.	9400000.	67828.	23.39	208.26
2015	550000.	9950000.	63022.	25.09	206.13
2016	550000.	10500000.	58557.	26.80	204.00
2017	550000.	11050000.	54409.	28.50	201.87
2018	483000.	11533000.	44395.	30.00	200.00
2019	0.	11533000.	0.	30.00	200.00
2020	0.	11533000.	0.	30.00	200.00
2021	0.	11533000.	0.	30.00	200.00
2022	0.	11533000.	0.	30.00	200.00
2023	0.	11533000.	0.	30.00	200.00
2024	0.	11533000.	0.	30.00	200.00
2025	0.	11533000.	0.	30.00	200.00
2026	0.	11533000.	0.	30.00	200.00
2027	0.	11533000.	0.	30.00	200.00
2028	0.	11533000.	0.	30.00	200.00
2029	0.	11533000.	0.	30.00	200.00
2030	0.	11533000.	0.	30.00	200.00
TOTAL	11533000.		2769587.		

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EXAMPLE ONE - D2M2 USERS MANUAL
ANALYSIS OF CONTINUOUS OPERATION

32

DREDGED-MATERIAL SOURCE/DISPOSAL SITE
SUMMARY REPORT

DISPOSAL SITE ID	DREDGING VOLUMES (C.Y.) AND BEGINNING/ENDING TIME PERIODS								
	WILMHA	WILMBO							TOTAL
OCEAN1	6600000. 2019/2030	6734000. 2018/2030	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	13334000.
WILSUD	14390000. 1990/2018	8676000. 2003/2018	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	23066000.
WILHAR	0. 0/ 0	11540000. 1983/2003	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	11540000.
EDGEWD	7060000. 1981/1990	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	7060000.
TOTAL	28050000.	26950000.	0.	0.	0.	0.	0.	0.	55000000.

EXAMPLE ONE - D2M2 USERS MANUAL
ANALYSIS OF CONTINUOUS OPERATION

DISPOSAL SITE USAGE CHART

```
DISPOSAL
  SITE
   ID
         .
         .
OCEAN1   .                                       XXXXXXXXXXXXX
         .
         .
WILSUD   .          X  XX  XX  XXXXXXXXXXXXXXXXXX
         .
         .
WILHAR   .  XXX XX  XX  XX  XX  X
         .
         .
EDGEWD   .XXX XXX XX
         .
         I----I----I----I----I----I----I----I----I----I----I
       1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030

                                TIME
```

(33)

EXAMPLE TWO: ANALYSIS OF OPERATION WITH RESTART

This example illustrates the "restart" capability of program D2M2. With this capability, the program automatically can be executed recursively, with the final status of disposal sites from one execution serving as the initial condition for the next execution. The system considered in this example is the same as that considered in example one, but instead of analyzing 50 periods of operation, each one year in duration, two successive 25-period operations are analyzed. The first analysis determines the least-costly system operation of the system for 1981-2005. Program D2M2 then prepares an input file for analysis of system operation for 2006-2030. The initial conditions specified in this input file are the final conditions for 2005, as determined from the first analysis. This is illustrated by Fig. 5.

The program user must issue appropriate job-control commands to execute program D2M2 with the program-prepared input file. The commands should accomplish the following: (1) save the program-prepared restart input file, TAPE11, from the first execution; (2) rewind TAPE11; and (3) execute D2M2 with input read from TAPE11.

Item 34 is the user-prepared input file for analysis of 1981-2005 operation. This input file is essentially the same as the input file for example one. However, the specified period of analysis is 25 periods (field 1 of card 4). The value in field 10 of card 4 specifies that D2M2 is to prepare an input file to permit analysis of 25 additional periods with subsequent execution of the program. Volumes are specified on DV cards for each dredge site for only 25 periods (cards 40-42 and 48-50). The volumes specified for each site on DV cards of the program-generated file correspond to the final value shown on the DV cards of this initial input file (550,000 volume units per period for both sites). Field 3 is blank on the SX cards for the Ocean, Williamson Harbor South, and Williamson Harbor disposal areas (cards 13, 19, and 25). This indicates that these sites are available throughout the original 25-period analysis and the subsequent 25-period analysis performed when the program is restarted with the program-generated file. The lease for the Edgewood site is renegotiated in 1999, and that site too is available throughout the remainder of the analysis.

Disposal-site input reports and dredge-site input reports similar to those of example one are printed but are not included here. The volumes shown in the dredge site reports are those specified for 1981-2005.

Item 35 is the capacity expansion iteration log for analysis of the system operation for 1981-2005. As with example one, this serves as a summary of costs. This total net cost shown is the sum of acquisition, lease renegotiation, OMR, and operation costs for 1981-2005 inclusive. The present value calculations use the first period of analysis, 1981, as the base period.

System operation for the 25 periods, 1981-2005, is summarized by the tabular and graphical summaries identified as items 36 and 37.

A restart input file is prepared by D2M2 to allow analysis of operation for 25 subsequent periods beginning with 2006. This file is shown as item 38. Field 10 of the J1 card (card 4) indicates that 1981 is to be used as

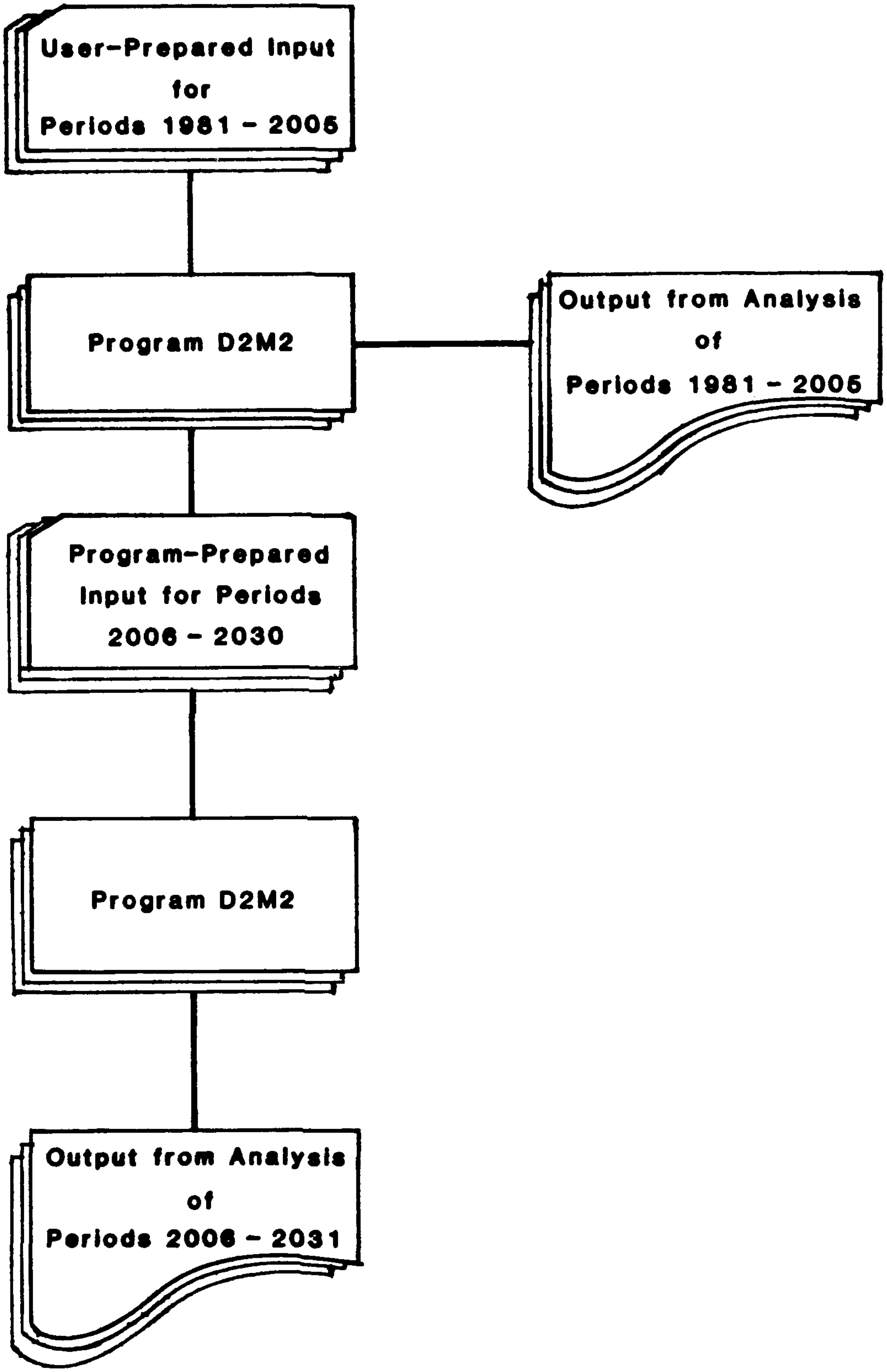

FIG. 5. - Schematic of Restarting Execution of Program D2M2
for Example Two

the base year for cost amortization. The initial storage for each disposal site is specified in field 3 of the SL card for each site (cards 18, 24, and 30). The volume to be dredged at the Williamson Harbor dredging site and disposed each period is 550,000 CY, and the volume to be dredged and disposed from the Williamson Harbor B site is 550,000 CY. These values, specified oncards 40 and 46, respectively, correspond to the values previously specified for each site for the final period of the initial analysis (2005).

Item 39 is the capacity expansion iteration log for analysis of system operation for 2006-2030. The acquisition, renegotiation, and OMR costs shown are the 1981 present-value equivalents of any such costs incurred in 2006-2030. The operation cost shown is the 1981 present-value equivalent of operation in 2006-2030. Consequently, the total net cost shown is comparable to total net cost computed for 1981-2005 in the initial analysis. The total-net-cost values can be added directly to determine total cost for 1981-2030 with the operation shown.

The operation for periods 2006-2030 is summarized by items 40 and 41.

Comparison of example one results with example two results shows that the disaggregated analysis may not yield the optimal operation scheme. The cost of this optimal operation scheme for 50 consecutive periods is $31.7 million while the sum of the cost for the two consecutive 25-period operations is $32.8 million. This is expected; in example two, analysis of the first 25-period operation cannot consider the disposal requirements of the second 25 periods. In example one, the disposal requirements of all 50 periods are considered simultaneously, so disposal site capacity can be allocated more efficiently. However the restarting procedure may provide the only means to analyze long-term operation of a system which includes a large number of dredge sites and disposal sites. Then the near-optimal solution may be acceptable.

```
** LIST OF RECORDS READ BY READIN **
RECORD
 ORDER          1         2         3         4         5         6         7         8
NUMBER 12345678901234567890123456789012345678901234567890123456789012345678901234567890

     1 T1      EXAMPLE TWO - D2M2 USERS MANUAL
     2 T2      ANALYSIS OF OPERATION WITH RESTART
     3 T3
     4 J1    25    1981   7.625       4       2       2                      15      25
     5 TIHOPGOV  GOVERNMENT HOPPER DREDGE
     6 TD  5280   52800   79200  105600  158400  211200  264000  316800  422400  528000
     7 TC  1.40    3.00    3.90    4.75    6.60    8.40   10.20   11.95   15.60   19.30
     8 TI16PIPM  16-INCH PIPELINE DREDGE
     9 TD     0    1000    3000    6950    7000   13950   14000   20950   21000   28000
    10 TC     0    0.75    0.90    1.50    2.00    2.40    2.75    3.25    3.60    4.70
    11 SIOCEAN1  OCEAN SITE ONE
    12 SL  7000  500000
    13 SX
    14 SSOCEAN1       099999999
    15 SEOCEAN1       0      99
    16 SAOCEAN1       0     626
    17 SIWILSUD  WILLIAMSON HARBOR SOUTH DISPOSAL AREA
    18 SL  5500    2500                     2.0             0.75
    19 SX     0    1987                                                         1725000
    20 SSWILSUD       0 5565000 895200011533000
    21 SEWILSUD      -3      12      22      30
    22 SAWILSUD     230     230     210     200
    23 SIWILHAR  WILLIAMSON HARBOR DISPOSAL AREA
    24 SL  1000       0                     2.0             0.60
    25 SX
    26 SSWILHAR       0 1075000 1575000 2875000 5770000
    27 SEWILHAR      28      32      38      40      50
    28 SAWILHAR       0     165     173     176     174
    29 SIEDGEWD  EDGEWOOD DISPOSAL AREA
    30 SL  4000                             2.0             0.60
    31 SX     1                    1999    0000
    32 SSEDGEWD       0  130000  930000 1130000 3530000
    33 SEEDGEWD       0      35      40      41      50
    34 SAEDGEWD       0      62     210     212     210
    35 DIWILMHA  WILLIAMSON HARBOR DREDGING SITE
    36 DL  3000               3
    37 DTEDGEWD  16PIPM
    38 DTOCEAN1  HOPGOV
    39 DTWILSUD  16PIPM
    40 DV       1100000 1100000  550000       0  550000 1100000  550000       0 1100000
    41 DV       1100000       0       0 1100000 1100000       0       0 1100000 1100000
    42 DV             0       0 1100000 1100000       0       0  550000
    43 DIWILMBO  WILLIAMSON HARBOR B DREDGING SITE
    44 DL  3000               3
    45 DTWILSUD  16PIPM
    46 DTWILHAR  16PIPM
    47 DTOCEAN1  HOPGOV
    48 DV             0       0  550000 1100000  550000       0  550000 1100000       0
    49 DV             0 1100000 1100000       0       0 1100000 1100000       0       0
    50 DV       1100000 1100000       0       0 1100000 1100000  550000

READIN --    50 RECORDS WRITTEN TO LOGICAL FILE 12
```

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EXAMPLE TWO - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH RESTART

CAPACITY EXPANSION ITERATION LOG

ITER	SITE ID	SITE ACQ. PERIOD	LEASE TERM. PER.	SITE TERM. PER.	PRESENT VALUE ACQ.+RENEG.+OMR COST	PRESENT VALUE OPERATION COST	TOTAL NET COST
0	OCEAN1	1981	2031	2031			
	WILSUD	1987	2031	2031			
	WILHAR	1981	2031	2031			
	EDGEWD	1981	1999	2031	1112443.	18126162.	19238604.

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EXAMPLE TWO - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH RESTART

36

DREDGED-MATERIAL SOURCE/DISPOSAL SITE
SUMMARY REPORT

DISPOSAL SITE ID	DREDGING VOLUMES (C.Y.) AND BEGINNING/ENDING TIME PERIODS								
	WILMHA	WILMBO							TOTAL
OCEAN1	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0.
WILSUD	7240000. 1990/2005	1660000. 2003/2005	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	8900000.
WILHAR	0. 0/ 0	11540000. 1983/2003	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	11540000.
EDGEWD	7060000. 1981/1990	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	7060000.
TOTAL	14300000.	13200000.	0.	0.	0.	0.	0.	0.	27500000.

EXAMPLE TWO - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH RESTART

DISPOSAL SITE USAGE CHART

```
DISPOSAL
  SITE
   ID
             .
             .
OCEAN1       .
             .
             .
             .
WILSUD       .          X  XX  XX  XXXXX
             .
             .
WILHAR       .  XXX XX  XX  XX  XX  X
             .
             .
EDGEWD       .XXX XXX XX
             .
             I----I----I----I----I----I
          1980 1985 1990 1995 2000 2005

                                 TIME
```

37

```
** LIST OF RECORDS READ BY READIN **
RECORD
 ORDER          1         2         3         4         5         6         7         8
NUMBER 12345678901234567890123456789012345678901234567890123456789012345678901234567890

     1 T1       EXAMPLE TWO - D2M2 USERS MANUAL
     2 T2       ANALYSIS OF OPERATION WITH RESTART
     3 T3
     4 J1     25      2006     7.625         4         2         2                  15     -1981
     5 TIHOPGOV  GOVERNMENT HOPPER DREDGE
     6 TD   5280     52800     79200    105600    158400    211200    264000    316800    422400    528000
     7 TC   1.40      3.00      3.90      4.75      6.60      8.40     10.20     11.95     15.60     19.30
     8 TI16PIPM  16-INCH PIPELINE DREDGE
     9 TD      0      1000      3000      6950      7000     13950     14000     20950     21000     28000
    10 TC      0      0.75      0.90      1.50      2.00      2.40      2.75      3.25      3.60      4.70
    11 SIOCEAN1  OCEAN SITE ONE
    12 SL   7000    500000                   0
    13 SX             1981
    14 SSOCEAN1         099999999
    15 SEOCEAN1         0        99
    16 SAOCEAN1         0       626
    17 SIWILSUD  WILLIAMSON HARBOR SOUTH DISPOSAL AREA
    18 SL   5500      2500             4450000       2.0                0.75
    19 SX      0      1987                                                                     1725000
    20 SSWILSUD         0   5565000 895200011533000
    21 SEWILSUD        -3        12        22        30
    22 SAWILSUD       230       230       210       200
    23 SIWILHAR  WILLIAMSON HARBOR DISPOSAL AREA
    24 SL   1000         0             5770000       2.0                0.60
    25 SX             1981
    26 SSWILHAR         0   1075000   1575000   2875000   5770000
    27 SEWILHAR        28        32        38        40        50
    28 SAWILHAR         0       165       173       176       174
    29 SIEDGEWD  EDGEWOOD DISPOSAL AREA
    30 SL   4000                       3530000       2.0                0.60
    31 SX      1      1981                1999     10000
    32 SSEDGEWD         0    130000    930000   1130000   3530000
    33 SEEDGEWD         0        35        40        41        50
    34 SAEDGEWD         0        62       210       212       210
    35 DIWILMHA  WILLIAMSON HARBOR DREDGING SITE
    36 DL   3000                 3
    37 DTEDGEWD  16PIPM
    38 DTOCEAN1  HOPGOV
    39 DTWILSUD  16PIPM
    40 DV        550000.        -1
    41 DIWILMBO  WILLIAMSON HARBOR B DREDGING SITE
    42 DL   3000                 3
    43 DTWILSUD  16PIPM
    44 DTWILHAR  16PIPM
    45 DTOCEAN1  HOPGOV
    46 DV        550000.        -1

 READIN --    46 RECORDS WRITTEN TO LOGICAL FILE 12
```

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EXAMPLE TWO - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH RESTART

39

CAPACITY EXPANSION ITERATION LOG

ITER	SITE ID	SITE ACQ. PERIOD	LEASE TERM. PER.	SITE TERM. PER.	PRESENT VALUE ACQ.+RENEG.+OMR COST	PRESENT VALUE OPERATION COST	TOTAL NET COST
0	OCEAN1	1981	2031	2031			
	WILSUD	1987	2031	2031			
	WILHAR	1981	2031	2031			
	EDGEWD	1981	1999	2031	0.	12459535.	12459535.

EXAMPLE TWO - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH RESTART

40

DREDGED-MATERIAL SOURCE/DISPOSAL SITE
SUMMARY REPORT

DISPOSAL SITE ID	DREDGING VOLUMES (C.Y.) AND BEGINNING/ENDING TIME PERIODS								
	WILMHA	WILMBO							TOTAL
OCEAN1	6734000. 2018/2030	6600000. 2019/2030	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	13334000.
WILSUD	7016000. 2006/2018	7150000. 2006/2018	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	14166000.
WILHAR	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0.
EDGEWD	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0.
TOTAL	13750000.	13750000.	0.	0.	0.	0.	0.	0.	27500000.

EXAMPLE TWO - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH RESTART

DISPOSAL SITE USAGE CHART

```
DISPOSAL
  SITE
   ID
           .
           .
OCEAN1     .            XXXXXXXXXXXXX
           .
           .
WILSUD     .XXXXXXXXXXXXX
           .
           .
WILHAR     .
           .
           .
EDGEWD     .
           .
           I----I----I----I----I----I
          2005 2010 2015 2020 2025 2030

                                   TIME
```

41

Example Three: ANALYSIS OF OPERATION WITH DISPOSAL SITE RESTING.

In practice, dredged-materal disposal sites generally are not used continuously. Instead sites are "rested" following use; the sites are allowed to dry and maintenance is performed as necessary. This operation practice is simulated in program D2M2 with cycles of availability and non-availability of sites. This example illustrates analysis of system operation with site resting. The system analyzed is the same system considered in example one, but the Edgewoode site is rested for two periods of each five.

Item 42 is the user-prepared input for example three. This input file is essentially the same as the input file for example one. The resting of the Edgewood disposal area is specified in field 2 of the SX card for that site (card 31). The value in columns 9 and 10 indicates the site is available for three periods prior to resting, and the value in columns 11 and 12 indicates the site is rested for two periods. This cycle is repeated while the site is available (1981-2030).

As with example one, disposal-site and dredge-site input reports are printed; these are not included here. Likewise, disposal-site status reports are printed for each site; these are also omitted.

Items 43, 44, and 45 summarize system operation for example three. The same volume of material is disposed in each site as in example one (see item 44), but the timing of the disposing is different due to the resting of the Edgewood site (see item 45). The total system net cost is $37.8 million (item 43), which exceeds the cost of optimal operation in example one.

```
** LIST OF RECORDS READ BY READIN **
RECORD
 ORDER          1         2         3         4         5         6         7         8
NUMBER 12345678901234567890123456789012345678901234567890123456789012345678901234567890

     1 T1      EXAMPLE THREE - D2M2 USERS MANUAL
     2 T2      ANALYSIS OF OPERATION WITH DISPOSAL RESTING
     3 T3
     4 J1    50    1981   7.625       4       2       2                      15
     5 TIHOPGOV  GOVERNMENT HOPPER DREDGE
     6 TD  5280   52800   79200  105600  158400  211200  264000  316800  422400  528000
     7 TC  1.40    3.00    3.90    4.75    6.60    8.40   10.20   11.95   15.60   19.30
     8 TI16PIPM  16-INCH PIPELINE DREDGE
     9 TD     0    1000    3000    6950    7000   13950   14000   20950   21000   28000
    10 TC     0    0.75    0.90    1.50    2.00    2.40    2.75    3.25    3.60    4.70
    11 SIOCEAN1  OCEAN SITE ONE
    12 SL  7000  500000
    13 SX
    14 SSOCEAN1       099999999
    15 SEOCEAN1       0      99
    16 SAOCEAN1       0     626
    17 SIWILSUD  WILLIAMSON HARBOR SOUTH DISPOSAL AREA
    18 SL  5500    2500                     2.0            0.75
    19 SX     0    1987                                                         1725000
    20 SSWILSUD       0 5565000 895200011533000
    21 SEWILSUD      -3      12      22      30
    22 SAWILSUD     230     230     210     200
    23 SIWILHAR  WILLIAMSON HARBOR DISPOSAL AREA
    24 SL  1000       0                     2.0            0.60
    25 SX
    26 SSWILHAR       0 1075000 1575000 2875000 5770000
    27 SEWILHAR      28      32      38      40      50
    28 SAWILHAR       0     165     173     176     174
    29 SIEDGEWD  EDGEWOOD DISPOSAL AREA
    30 SL  4000                             2.0            0.60
    31 SX     103021981            1999   10000
    32 SSEDGEWD       0  130000  930000 1130000 3530000
    33 SEEDGEWD       0      35      40      41      50
    34 SAEDGEWD       0      62     210     212     210
    35 DIWILMHA  WILLIAMSON HARBOR DREDGING SITE
    36 DL  3000               3
    37 DTEDGEWD  16PIPM
    38 DTOCEAN1  HOPGOV
    39 DTWILSUD  16PIPM
    40 DV       1100000 1100000  550000       0  550000 1100000  550000       0 1100000
    41 DV       1100000       0       0 1100000 1100000       0       0 1100000 1100000
    42 DV             0       0 1100000 1100000       0       0  550000  550000  550000
    43 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
    44 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
    45 DV        550000  550000  550000  550000  550000
    46 DIWILMBO  WILLIAMSON HARBOR B DREDGING SITE
    47 DL  3000               3
    48 DTWILSUD  16PIPM
    49 DTWILHAR  16PIPM
    50 DTOCEAN1  HOPGOV
    51 DV             0       0  550000 1100000  550000       0  550000 1100000       0
    52 DV             0 1100000 1100000       0       0 1100000 1100000       0       0
    53 DV       1100000 1100000       0       0 1100000 1100000  550000  550000  550000
    54 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
    55 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
    56 DV        550000  550000  550000  550000  550000

READIN --    56 RECORDS WRITTEN TO LOGICAL FILE 12
```

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EXAMPLE THREE - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH DISPOSAL RESTING

43

CAPACITY EXPANSION ITERATION LOG

ITER	SITE ID	SITE ACQ. PERIOD	LEASE TERM. PER.	SITE TERM. PER.	PRESENT VALUE ACQ.+RENEG.+OMR COST	PRESENT VALUE OPERATION COST	TOTAL NET COST
0	OCEAN1	1981	2031	2031			
	WILSUD	1987	2031	2031			
	WILHAR	1981	2031	2031			
	EDGEWD	1981	1999	2031	1112443.	36691215.	37803658.

EXAMPLE THREE - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH DISPOSAL RESTING

44

DREDGED-MATERIAL SOURCE/DISPOSAL SITE
SUMMARY REPORT

DISPOSAL SITE ID	DREDGING VOLUMES (C.Y.) AND BEGINNING/ENDING TIME PERIODS								TOTAL
	WILMHA	WILMBO							
OCEAN1	6734000. 1985/2030	6600000. 2019/2030	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	13334000.
WILSUD	14256000. 1989/2019	8810000. 2003/2018	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	23066000.
WILHAR	0. 0/ 0	11540000. 1983/2003	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	11540000.
EDGEWD	7060000. 1981/1998	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	7060000.
TOTAL	28050000.	26950000.	0.	0.	0.	0.	0.	0.	55000000.

EXAMPLE THREE - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH DISPOSAL RESTING

DISPOSAL SITE USAGE CHART

```
DISPOSAL
  SITE
   ID
         .
         .
OCEAN1   .   X                                 XXXXXXXXXXXX
         .
         .
WILSUD   .         XX   X   X  XXXXXXXXXXXXXXXXXXX
         .
         .
WILHAR   .  XXX XX  XX  XX  XX  X
         .
         .
EDGEWD   .XXX  XX     X   XX
         .
         I----I----I----I----I----I----I----I----I----I----I
       1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030

                            TIME
```

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Example Four: ANALYSIS OF OPERATION WITH PARTIAL SOLUTION SPECIFIED.

Due to non-economic factors, operation policies that are not the least-costly policies are sometimes necessary. These policies can be simulated with program D2M2 by specifying the volume of material that is to be transported in a specified period from a dredging site to a disposal site. Example four illustrates this.

The disposal system modeled in example four is the same system modeled in example one, and cards 1-56 of the input (item 46) are identical to cards 1-56 of the input for example 1. The required system operation is shown in Table 2. This operation is specified on cards 57-62. Each card specifies a dredged-material source, disposal site, period, and volume. In this example, no alternative transporation types exist between pairs of dredging sites and disposal sites, so transportation types need not be specified (field 5 of FS card). When a partial solution is specified, the user must specify a solution that is feasible: the disposal site and dredge site must be available and must be linked, and the transportation link and the disposal site capacities must not be exceeded by the volume specified.

Disposal site input reports and dredge site input reports similar to those of example one are printed but are not included here. Likewise a system volume report is printed, but is not included here.

Item 47 is the capacity expansion iteration log, which serves here as a summary of system costs. The present value of the operation cost shown here represents the least cost for operation of the system, given the required operation specified on the FS cards.

Items 48 and 49 are the components of the operation report for the Williamson Harbor South disposal site. Similar reports are printed for the other disposal sites, but these are not reproduced here. The volumes transported to this site from the Williamson Harbor dredging site in 1987, 1989, 1990, 2029 and 2030 are volumes specified on the FS cards. The status of the disposal site with this operation can be compared with the status of the same site without the forced operation by referring to items 22-31 of example one. In example one, the site filled in 2018 and thus was not available for use from 2019 to 2030. However in example four, the requirement that 550,000 be transported from the Williamson Harbor dredging site and disposed at the Williamson Harbor South site in both 2029 and 2030 precludes this. The disposal site must have space available to store the material. This is accomplished by adding material to the site until 2017, reserving capacity to store the material deposited in 2019 and 2030. The site is filled then in 2030.

System operation for example four is summarized in the dredged-material source/disposal site summary report and the disposal site usage chart, included as items 50 and 51.

TABLE 2. - Required Operation for Example Four

Period (1)	Dredged-material source (2)	Disposal site (3)	Volume, in cubic yards (4)
1987	Williamson Harbor	Williamson Harbor South	550,000
1989	Williamson Harbor	Williamson Harbor South	1,100,000
1990	Williamson Harbor	Williamson Harbor South	1,100,000
2029	Williamson Harbor	Williamson Harbor South	550,000
2030	Williamson Harbor	Williamson harbor South	550,000

```
** LIST OF RECORDS READ BY READIN **
RECORD
 ORDER          1         2         3         4         5         6         7         8
NUMBER 12345678901234567890123456789012345678901234567890123456789012345678901234567890

     1 T1      EXAMPLE FOUR - D2M2 USERS MANUAL
     2 T2      ANALYSIS OF OPERATION WITH PARTIAL SOLUTION SPECIFIED
     3 T3
     4 J1      50  1981   7.625       4       2       2                      15
     5 TIHOPGOV  GOVERNMENT HOPPER DREDGE
     6 TD    5280 52800   79200  105600  158400  211200  264000  316800  422400  528000
     7 TC    1.40  3.00    3.90    4.75    6.60    8.40   10.20   11.95   15.60   19.30
     8 TI16PIPM  16-INCH PIPELINE DREDGE
     9 TD       0  1000    3000    6950    7000   13950   14000   20950   21000   28000
    10 TC       0  0.75    0.90    1.50    2.00    2.40    2.75    3.25    3.60    4.70
    11 SIOCEAN1  OCEAN SITE ONE
    12 SL    7000500000
    13 SX
    14 SSOCEAN1       099999999
    15 SEOCEAN1       0      99
    16 SAOCEAN1       0     626
    17 SIWILSUD  WILLIAMSON HARBOR SOUTH DISPOSAL AREA
    18 SL    5500  2500                     2.0            0.75
    19 SX       0  1987                                                         1725000
    20 SSWILSUD       0 5565000 895200011533000
    21 SEWILSUD      -3      12      22      30
    22 SAWILSUD     230     230     210     200
    23 SIWILHAR  WILLIAMSON HARBOR DISPOSAL AREA
    24 SL    1000     0                     2.0            0.60
    25 SX
    26 SSWILHAR       0 1075000 1575000 2875000 5770000
    27 SEWILHAR      28      32      38      40      50
    28 SAWILHAR       0     165     173     176     174
    29 SIEDGEWD  EDGEWOOD DISPOSAL AREA
    30 SL    4000                           2.0            0.60
    31 SX       1                  1999   10000
    32 SSEDGEWD       0  130000  930000 1130000 3530000
    33 SEEDGEWD       0      35      40      41      50
    34 SAEDGEWD       0      62     210     212     210
    35 DIWILMHA  WILLIAMSON HARBOR DREDGING SITE
    36 DL    3000             3
    37 DTEDGEWD  16PIPM
    38 DTOCEAN1  HOPGOV
    39 DTWILSUD  16PIPM
    40 DV       1100000 1100000  550000       0  550000 1100000  550000       0 1100000
    41 DV       1100000       0       0 1100000 1100000       0       0 1100000 1100000
    42 DV             0       0 1100000 1100000       0       0  550000  550000  550000
    43 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
    44 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
    45 DV        550000  550000  550000  550000  550000
    46 DIWILMBO  WILLIAMSON HARBOR B DREDGING SITE
    47 DL    3000             3
    48 DTWILSUD  16PIPM
    49 DTWILHAR  16PIPM
    50 DTOCEAN1  HOPGOV
    51 DV             0       0  550000 1100000  550000       0  550000 1100000       0
    52 DV             0 1100000 1100000       0       0 1100000 1100000       0       0
    53 DV       1100000 1100000       0       0 1100000 1100000  550000  550000  550000
    54 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
    55 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
    56 DV        550000  550000  550000  550000  550000
    57 FSWILMHA  WILSUD    1987 550000.
    58 FSWILMHA  WILSUD    19891100000.
    59 FSWILMHA  WILSUD    19901100000.
    60 FSWILMHA  WILSUD    2029 550000.
    61 FSWILMHA  WILSUD    2030 550000.

READIN --    61 RECORDS WRITTEN TO LOGICAL FILE 12
```

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EXAMPLE FOUR - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH PARTIAL SOLUTION SPECIFIED

47

CAPACITY EXPANSION ITERATION LOG

ITER	SITE ID	SITE ACQ. PERIOD	LEASE TERM. PER.	SITE TERM. PER.	PRESENT VALUE ACQ.+RENEG.+OMR COST	PRESENT VALUE OPERATION COST	TOTAL NET COST
0	OCEAN1	1981	2031	2031			
	WILSUD	1987	2031	2031			
	WILHAR	1981	2031	2031			
	EDGEWD	1981	1999	2031	1112443.	31491646.	32604089.

EXAMPLE FOUR - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH PARTIAL SOLUTION SPECIFIED

DISPOSAL SITE = WILSUD   WILLIAMSON HARBOR SOUTH DISPOSAL AREA

ACQUISITION PERIOD = 1987   WET-TO-DRY RATIO = 2.00

NOTE - MATERIAL FROM DREDGE SITES IS WET.
TRANSFERRED MATERIAL IS DRY.

MATERIAL ADDED
SOLUTION FOR ITERATION = 0

48

SITE ID	WILMHA 16PIPM		WILMBO 16PIPM				TOTAL		
PERIOD	VOLUME	COST	VOLUME	COST	VOLUME	COST	VOLUME	COST	
1981	0.	0.	0.	0.	0.	0.	0.	0.	
1982	0.	0.	0.	0.	0.	0.	0.	0.	
1983	0.	0.	0.	0.	0.	0.	0.	0.	
1984	0.	0.	0.	0.	0.	0.	0.	0.	
1985	0.	0.	0.	0.	0.	0.	0.	0.	
1986	0.	0.	0.	0.	0.	0.	0.	0.	
1987	550000.	395844.	0.	0.	0.	0.	550000.	395844.	
1988	0.	0.	0.	0.	0.	0.	0.	0.	
1989	1100000.	683483.	0.	0.	0.	0.	1100000.	683483.	
1990	1100000.	635060.	0.	0.	0.	0.	1100000.	635060.	
1991	0.	0.	0.	0.	0.	0.	0.	0.	
1992	0.	0.	0.	0.	0.	0.	0.	0.	
1993	0.	0.	0.	0.	0.	0.	0.	0.	
1994	0.	0.	0.	0.	0.	0.	0.	0.	
1995	0.	0.	0.	0.	0.	0.	0.	0.	
1996	0.	0.	0.	0.	0.	0.	0.	0.	
1997	640000.	220907.	0.	0.	0.	0.	640000.	220907.	
1998	1100000.	352784.	0.	0.	0.	0.	1100000.	352784.	
1999	0.	0.	0.	0.	0.	0.	0.	0.	
2000	0.	0.	0.	0.	0.	0.	0.	0.	
2001	1100000.	282989.	0.	0.	0.	0.	1100000.	282989.	
2002	1100000.	262940.	0.	0.	0.	0.	1100000.	262940.	
2003	0.	0.	10000.	2221.	0.	0.	10000.	2221.	
2004	0.	0.	1100000.	227002.	0.	0.	1100000.	227002.	
2005	550000.	105460.	550000.	105460.	0.	0.	1100000.	210920.	
2006	550000.	97988.	550000.	97988.	0.	0.	1100000.	195976.	
2007	550000.	91046.	550000.	91046.	0.	0.	1100000.	182092.	
2008	550000.	84596.	550000.	84596.	0.	0.	1100000.	169191.	
2009	550000.	78602.	550000.	78602.	0.	0.	1100000.	157204.	
2010	550000.	73033.	550000.	73033.	0.	0.	1100000.	146067.	
2011	550000.	67859.	550000.	67859.	0.	0.	1100000.	135718.	
2012	550000.	63051.	550000.	63051.	0.	0.	1100000.	126103.	
2013	550000.	58584.	550000.	58584.	0.	0.	1100000.	117169.	
2014	550000.	54434.	550000.	54434.	0.	0.	1100000.	108868.	
2015	550000.	50577.	550000.	50577.	0.	0.	1100000.	101155.	
2016	550000.	46994.	550000.	46994.	0.	0.	1100000.	93988.	
2017	550000.	43665.	416000.	33026.	0.	0.	966000.	76691.	
2018	0.	0.	0.	0.	0.	0.	0.	0.	
2019	0.	0.	0.	0.	0.	0.	0.	0.	
2020	0.	0.	0.	0.	0.	0.	0.	0.	
2021	0.	0.	0.	0.	0.	0.	0.	0.	
2022	0.	0.	0.	0.	0.	0.	0.	0.	
2023	0.	0.	0.	0.	0.	0.	0.	0.	
2024	0.	0.	0.	0.	0.	0.	0.	0.	
2025	0.	0.	0.	0.	0.	0.	0.	0.	
2026	0.	0.	0.	0.	0.	0.	0.	0.	
2027	0.	0.	0.	0.	0.	0.	0.	0.	
2028	0.	0.	0.	0.	0.	0.	0.	0.	
2029	550000.	18079.	0.	0.	0.	0.	550000.	18079.	
2030	550000.	16798.	0.	0.	0.	0.	550000.	16798.	FILLED
TOTAL	14940000.	3784773.	8126000.	1134474.	0.	0.	23066000.	4919247.	

DISPOSAL SITE STATUS (DRY)
SOLUTION FOR ITERATION = 0

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PERIOD	VOLUME DISPOSED	END OF PER STORAGE	DISPOSAL COST	ELEVATION	SURFACE AREA
1981	0.	0.	0.	-3.00	230.00
1982	0.	0.	0.	-3.00	230.00
1983	0.	0.	0.	-3.00	230.00
1984	0.	0.	0.	-3.00	230.00
1985	0.	0.	0.	-3.00	230.00
1986	0.	0.	0.	-3.00	230.00
1987	275000.	275000.	246622.	-2.26	230.00
1988	0.	275000.	0.	-2.26	230.00
1989	550000.	825000.	425829.	-0.78	230.00
1990	550000.	1375000.	395660.	0.71	230.00
1991	0.	1375000.	0.	0.71	230.00
1992	0.	1375000.	0.	0.71	230.00
1993	0.	1375000.	0.	0.71	230.00
1994	0.	1375000.	0.	0.71	230.00
1995	0.	1375000.	0.	0.71	230.00
1996	0.	1375000.	0.	0.71	230.00
1997	320000.	1695000.	137631.	1.57	230.00
1998	550000.	2245000.	219795.	3.05	230.00
1999	0.	2245000.	0.	3.05	230.00
2000	0.	2245000.	0.	3.05	230.00
2001	550000.	2795000.	176310.	4.53	230.00
2002	550000.	3345000.	163819.	6.02	230.00
2003	5000.	3350000.	1384.	6.03	230.00
2004	550000.	3900000.	141429.	7.51	230.00
2005	550000.	4450000.	131409.	8.99	230.00
2006	550000.	5000000.	122099.	10.48	230.00
2007	550000.	5550000.	113448.	11.96	230.00
2008	550000.	6100000.	105411.	13.58	226.84
2009	550000.	6650000.	97943.	15.20	223.59
2010	550000.	7200000.	91004.	16.83	220.35
2011	550000.	7750000.	84556.	18.45	217.10
2012	550000.	8300000.	78566.	20.07	213.85
2013	550000.	8850000.	72999.	21.70	210.60
2014	550000.	9400000.	67828.	23.39	208.26
2015	550000.	9950000.	63022.	25.09	206.13
2016	550000.	10500000.	58557.	26.80	204.00
2017	483000.	10983000.	47781.	28.30	202.13
2018	0.	10983000.	0.	28.30	202.13
2019	0.	10983000.	0.	28.30	202.13
2020	0.	10983000.	0.	28.30	202.13
2021	0.	10983000.	0.	28.30	202.13
2022	0.	10983000.	0.	28.30	202.13
2023	0.	10983000.	0.	28.30	202.13
2024	0.	10983000.	0.	28.30	202.13
2025	0.	10983000.	0.	28.30	202.13
2026	0.	10983000.	0.	28.30	202.13
2027	0.	10983000.	0.	28.30	202.13
2028	0.	10983000.	0.	28.30	202.13
2029	275000.	11258000.	11264.	29.15	201.07
2030	275000.	11533000.	10466.	30.00	200.00
TOTAL	11533000.		3064831.		

EXAMPLE FOUR - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH PARTIAL SOLUTION SPECIFIED

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DREDGED-MATERIAL SOURCE/DISPOSAL SITE
SUMMARY REPORT

DISPOSAL SITE ID	DREDGING VOLUMES (C.Y.) AND BEGINNING/ENDING TIME PERIODS								
	WILMHA	WILMBO							TOTAL
OCEAN1	6050000. 2018/2028	7284000. 2017/2030	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	13334000.
WILSUD	14940000. 1987/2030	8126000. 2003/2017	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	23066000.
WILHAR	0. 0/ 0	11540000. 1983/2003	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	11540000.
EDGEWD	7060000. 1981/1997	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	7060000.
TOTAL	28050000.	26950000.	0.	0.	0.	0.	0.	0.	55000000.

EXAMPLE FOUR - D2M2 USERS MANUAL
ANALYSIS OF OPERATION WITH PARTIAL SOLUTION SPECIFIED

DISPOSAL SITE USAGE CHART

```
DISPOSAL
  SITE
   ID
          .
          .
OCEAN1    .                                    XXXXXXXXXXXXXX
          .
          .
WILSUD    .       X XX      XX  XXXXXXXXXXXXXXXXX           XX
          .
          .
WILHAR    .  XXX XX  XX  XX  XX  X
          .
          .
EDGEWD    .XXX XX      XX  X
          .
          I----I----I----I----I----I----I----I----I----I----I
        1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030

                            TIME
```

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Example Five: APPLICATION OF CAPACITY EXPANSION CAPABILITY

This example illustrates application of program D2M2 to select an economically efficient capacity-expansion schedule for a disposal system. The system, illustrated in Fig 5, includes two dredging sites, two existing disposal sites, three disposal sites that will be acquired in period 2000 for capacity expansion, and the Williamson Harbor South site, which may be acquired if economically justified. System operation for the period 1981-2030 is to be analyzed, but acquisition of the Williamson Harbor South site is considered only between 1981 and 2000 inclusive. Material from the two dredging sites is removed and transported to the disposal sites with a 16-inch or 27-inch pipeline dredge or a government-owned hopper dredge. The rates of required removal from the dredging site are the same as specified in example one.

Items 52 through 58 are reproductions of selected portions of the D2M2 output. Item 52 is a list of the program input. The input required to exercise the capacity-expansion capability of D2M2 is essentially the same as required to use D2M2 for evaluation of system operation; the exception is the manner in which the potential capacity expansion site is described. As with example one, title cards (cards 1-3) and a J1 card (card 4) are provided. On this J1 card, the total number of disposal sites (field 4) is the number of existing sites plus sites with specified future acquisition periods plus potential capacity expansion sites. A set of TI, TD, and TC cards is included for each dredging and transporting technique. If techniques not currently used may be used for expansion sites, these techniques must be specified here with TI, TD and TC cards. A set of SI, SL, SX, SS, SE, and SA cards are provided for each disposal site. Cards 20-25 and 26-31 are the disposal-site description cards for Williamson Harbor and Edgewood, the existing sites. The three sites for which future acquisition is specified and the potential expansion site likewise are described by data provided on SI, SL, SX, SS, SE, and SA cards (cards 14-19, 32-37, 38-43, and 44-49). For the capacity expansion site, the parameter IEXP (field 1 of the SX card) is three, indicating that the site may be acquired anytime between IPERA and IPERG, the specified earliest and latest possible period for acquisition. For this example, these periods are specified as 1981 and 2000, respectively.

The capacity-expansion iteration log shows the expansion plans that are selected and evaluated by the program and the results of each evaluation. For each iteration, the trial acqusition period for the site is shown (item 53). For the potential expansion site, this acquisition period changes from iteration to iteration. The lease termination period is identified for all sites (item 54). This is the period in which the lease terminates; the site then is no longer available for use unless the lease is renegotiated. For sites that are not leased, this is shown as the period following the study. After the termination period shown (item 55), the designated disposal site is no longer considered for use. For existing or possible capacity-expansion sites this is the last period of the study. For leased sites, this is the last period of the study if lease renegotiation is considered in the iteration; otherwise the site is unavailable after the lease termination period. Item 56 is the approximate total net cost of each alternative capacity-expansion plan evaluated. The estimated present value of acquisition cost, lease-renegotiation cost, OMR cost, and operation cost is included in this calculation. Acquisition cost is estimated as a function of system operation in all cases in which a specific acquisition period is not defined for all capacity expansion sites, so no cost breakdown is possible.

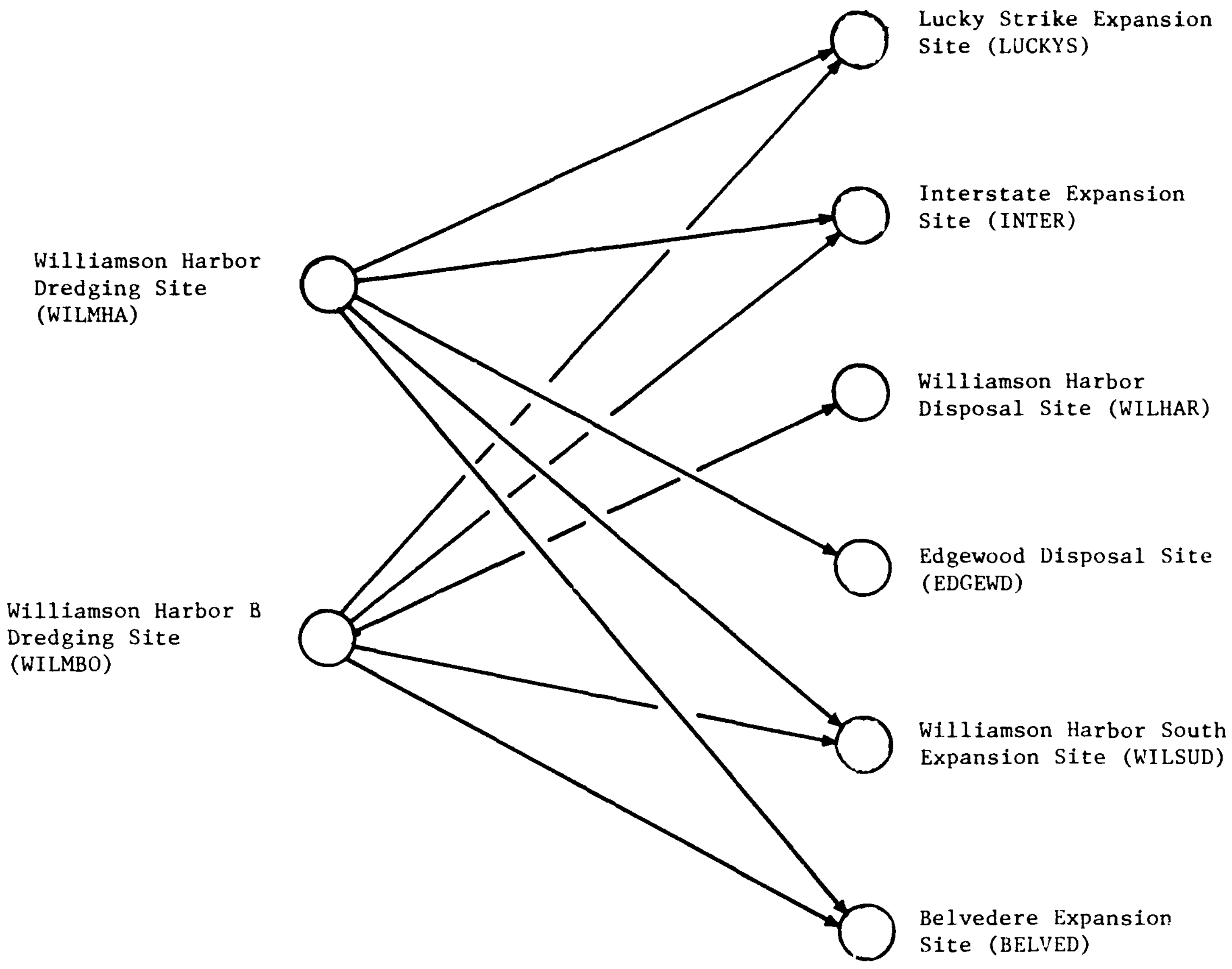

FIG. 6. - Disposal System for Example Five

For the example problem, the minimum-cost expansion scheme found calls for acquisition of the Williamson Harbor South site in 1990. The actual present value of total cost for this plan is $23786139, which includes acquisition cost and OMR cost of $892846 and operation cost of $22893294. These true costs are shown in the final row of the iteration log (item 57), which recapitulates the optimal solution. Identification of the optimal plan required 12 iterations as follows:

Iteration 0: Acquisition of the Williamson Harbor South site is considered at any time following the earliest specified date (1981). This includes not acquiring the site at all within the time horizon of this analysis. A network is formulated with the site available for all periods following 1981, and the acquisition cost is approximated as a function of the utilization of the site each period.

Iteration 1: At the beginning of each iteration, a capacity expansion site is selected as the candidate for acquisition period revision. In this case, only one potential site is defined, so its acquisition period is altered from 1981-2031 to 1981-2000. The latest acceptable period for acquisition of this site is 2000, so in this iteration, the efficiency of site acquisition within the specified allowable time window is evaluated.

Iteration 2: The utilization of the Williamson Harbor South site is evaluated. The site is not used extensively, so acquisition is postponed until it is 10% filled, in 1997. However acquisition in 1997 fails to provide capacity needed earlier, so this alternative is infeasible.

Iteration 3: The algorithm backtracks and considers acquisition between 1981 and 1996 after determining that acquisition after 1996 is infeasible. The approximate cost of this is $23500275.

Iteration 4: Utilization of the site in the previous iteration is considered. In 1990, the site was 10% filled, so acquisition is postponed until then, yielding an approximate cost of $23515395.

Iteration 5: In iteration 4, the site never filled to 10% of capacity between 1990 and 1996, so acquisition is postponed to at least period 1994. This is 67% of the time from 1990 to 1996, a percentage determined from experience. Unfortunately, such postponement is not feasible in this case.

Iteration 6: The procedure backtracks and considers acquisition between 1990 and 1993. This is feasible, and the approximate cost is $23661674.

Iteration 7: The site does not fill to 10% between 1990 and 1993, so acquisition is postponed using the 67%-criteria again. Again this is infeasible.

Iteration 8: The algorithm backtracks and evaluates the cost of acquisition between 1990 and 1991. The approximate cost is $23786634.

Iteration 9: Again the site does not fill to 10%, so again acquisition is postponed to 1991 with the 67%-criteria. This is infeasible. Note that this iteration yields a potential solution: acquire the site in 1991. However that solution is infeasible.

Iteration 10: Backtracking now requires evaluation of acquisition in 1990. This is feasible, and the cost is approximately $23786139. This is then a feasible acquisition plan: acquire the Williamson Harbor South site in 1990. However, without further evaluation, this cannot be declared the optimal solution.

Iteriation 11: The procedure requires backtracking to evaluate all as-yet unconsidered alternative solutions. Acquisition between 1981 and 1989 is one such solution. However the approximate cost exceeds the cost of the solution found in interation 10, so this solution, and any solution requiring acquisition between 1981 and 1989, can be eliminated from further consideration.

Iteration 12: The algorithm backtracks finally and considers non-acquisition, which is infeasible.

Following the capacity expansion iteration log, the usual disposal site reports and operation summaries (item 58 for example) are printed for the system with the optimal acquisition of expansion sites.

```
 1 T1              EXAMPLE FIVE - D2M2 USERS MANUAL
 2 T2        APPLICATION OF CAPACITY EXPANSION CAPABILITY
 3 T3
 4 J1     50    1981   7.625       6       2       3                      15
 5 TIHOPGOV  GOVERNMENT HOPPER DREDGE
 6 TD  5280   52800   79200  105600  158400  211200  264000  316800  422400  528000
 7 TC  1.40    3.00    3.90    4.75    6.60    8.40   10.20   11.95   15.60   19.30
 8 TI16PIPM  16-INCH PIPELINE DREDGE
 9 TD     0    1000    3000    6950    7000   13950   14000   20950   21000   28000
10 TC     0    0.75    0.90    1.50    2.00    2.40    2.75    3.25    3.60    4.70
11 TI27PIPL 27-INCH PIPELINE DREDGE
12 TD     0    1000    5500   10950   11000   21950   22000   32950   33000   40000
13 TC     0    0.65    0.90    1.50    2.10    2.55    3.00    3.60    4.10    4.60
14 SIWILSUD  WILLIAMSON HARBOR SOUTH DISPOSAL AREA
15 SL  5500    2500                     2.0             0.75
16 SX     3            2000                                                1725000
17 SSWILSUD       0 5565000 895200011533000
18 SEWILSUD      -3      12      22      30
19 SAWILSUD     230     230     210     200
20 SIWILHAR  WILLIAMSON HARBOR DISPOSAL AREA
21 SL  1000       0                     2.0             0.60
22 SX
23 SSWILHAR       0 1075000 1575000 2875000 5770000
24 SEWILHAR      28      32      38      40      50
25 SAWILHAR       0     165     173     176     174
26 SIEDGEWD  EDGEWOOD DISPOSAL AREA
27 SL  4000                             2.0             0.60
28 SX     1                    1999  10000.
29 SSEDGEWD       0  130000  930000 1130000 3530000
30 SEEDGEWD       0      35      40      41      50
31 SAEDGEWD       0      62     210     212     210
32 SILUCKY   LUCKY  STRIKE DISPOSAL SITE
33 SL  5500   14000                     2.0             0.60
34 SX     0    2000
35 SS             0 3500000
36 SE             0      26
37 SA           120     108
38 SIBELVED   BELVEDERE DISPOSAL SITE
39 SL  5000   28000                     1.5             0.75
40 SX     0    2000
41 SS             0  900000
42 SE             0      18
43 SA           140     127
44 SIINTER    INTERSTATE SITE
45 SL-13000   14000                     1.7             1.00
46 SX     0    2000
47 SS             0 3200000
48 SE           -10      10
49 SA           200     180
50 DIWILMHA  WILLIAMSON HARBOR DREDGING SITE
51 DL  3000               5
52 DTEDGEWD  16PIPM
53 DTWILSUD  16PIPM
54 DTLUCKY   16PIPM
55 DTBELVED  27PIPL
56 DTINTER   27PIPL
57 DV       1100000 1100000  550000       0  550000 1100000  550000       0 1100000
58 DV       1100000       0       0 1100000 1100000       0       0 1100000 1100000
59 DV             0       0 1100000 1100000       0       0  550000  550000  550000
60 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
61 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
62 DV        550000  550000  550000  550000  550000
63 DIWILMBO  WILLIAMSON HARBOR BOGUS DREDGING SITE
64 DL  3000               5
65 DTWILSUD  16PIPM
66 DTWILHAR  16PIPM
67 DTLUCKY   16PIPM
68 DTBELVED  27PIPL
69 DTINTER   27PIPL
70 DV             0       0  550000 1100000  550000       0  550000 1100000       0
71 DV             0 1100000 1100000       0       0 1100000 1100000       0       0
72 DV       1100000 1100000       0       0 1100000 1100000  550000  550000  550000
73 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
74 DV        550000  550000  550000  550000  550000  550000  550000  550000  550000
75 DV        550000  550000  550000  550000  550000

READIN --    75 RECORDS WRITTEN TO LOGICAL FILE 12
```

(52)

EXAMPLE FIVE - D2M2 USERS MANUAL
APPLICATION OF CAPACITY EXPANSION CAPABILITY

53 54 CAPACITY EXPANSION ITERATION LOG 56

55

ITER	SITE ID	SITE ACQ. PERIOD		LEASE TERM. PER.	SITE TERM. PER.	PRESENT VALUE ACQ.+RENEG.+OMR COST	PRESENT VALUE OPERATION COST	TOTAL NET COST	
0	WILSUD	1981	2031	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	23159250.	APPROXIMATION
1	WILSUD	1981	2000	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	23364387.	APPROXIMATION
2	WILSUD	1997	2000	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	****************	INFEASIBLE
3	WILSUD	1981	1996	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	23500275.	APPROXIMATION
4	WILSUD	1990	1996	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	23515395.	APPROXIMATION
5	WILSUD	1994	1996	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	****************	INFEASIBLE

6	WILSUD	1990	1993	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	23661624.	APPROXIMATION
7	WILSUD	1992	1993	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BFLVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	****************	INFEASIBLE
8	WILSUD	1990	1991	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	23786639.	APPROXIMATION
9	WILSUD	1991	1991	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	****************	INFEASIBLE
10	WILSUD	1990	1990	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	23786139.	
11	WILSUD	1981	1989	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	23909040.	APPROXIMATION
12	WILSUD	2031	2031	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	****************	****************	****************	INFEASIBLE
10	WILSUD	1990	1990	2031	2031				
	WILHAR	1981	1981	2031	2031				
	EDGEWD	1981	1981	1999	2031				
	LUCKY	2000	2000	2031	2031				
	BELVED	2000	2000	2031	2031				
	INTER	2000	2000	2031	2031	892846.	22893294.	23/86139.	

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EXAMPLE FIVE - D2M2 USERS MANUAL
APPLICATION OF CAPACITY EXPANSION CAPABILITY

DREDGED-MATERIAL SOURCE/DISPOSAL SITE
SUMMARY REPORT

DISPOSAL SITE ID	DREDGING VOLUMES (C.Y.) AND BEGINNING/ENDING TIME PERIODS								
	WILMHA	WILMBO							TOTAL
WILSUD	14256000. 1990/2018	8810000. 2003/2018	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	23066000.
WILHAR	0. 0/ 0	11540000. 1983/2003	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	11540000.
EDGEWD	7060000. 1981/1990	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	7060000.
LUCKY	3434000. 2018/2024	3566000. 2019/2025	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	7000000.
BELVED	550000. 2025/2025	800000. 2025/2026	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	1350000.
INTER	2750000. 2026/2030	2234000. 2026/2030	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	0. 0/ 0	4984000.
TOTAL	28050000.	26950000.	0.	0.	0.	0.	0.	0.	55000000.

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APPENDIX IV

D2M2 INPUT DESCRIPTION

INPUT DESCRIPTION

This appendix provides a detailed description of program D2M2 input requirements, by card and by variable. The requirements are summarized in Fig. 7. The field number shown for each variable designates the location of that variable on the input card. Of the 80 columns available, columns 1-2 are reserved for the card identifier and are referred to as field 0 (zero). Field 1 includes card columns 3-8. Fields 2-10 contain eight columns each. When necessary, an abbreviated field location description is used to identify variables; the card name is followed by a decimal point and the field number. For example, SL.8 refers to the eighth field on the SL card.

All variables with names beginning with I, J, K, L, M, or N are integers and must be right-justified without decimal points. In general, input values, both numerical and alphanumeric, should be right-justified in their fields, except for multiple field alphanumeric information.

Appropriate values for each variable are shown in the column headed VALUE. A "+" in the column indicates a non-negative value should be provided. A "-" indicates a negative value should be provided. In some cases, either non-negative or negative values are acceptable; the variable description specifies the interpretation of the values. The abbreviation "AN" identifies variables for which alphanumeric characters are to be specified.

TITLE

These required cards provide three lines of information at the top of each page of output.

T1, T2, T3, CARDS - TITLES

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	T1,T2, T3	Card identification.
1-10	TITLE	AN	Title information (center of title in card column 41).

JOB CONTROL

Values on this required card define the period of analysis, economic analysis parameters, the dimensions of the disposal system, and the output desired.

J1 CARD - JOB CARD

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	J1	Card identification.
1	NPER	+	Number of uniform time periods for which analysis is to be performed. These time periods may be of any duration. Maximum allowable value is 100.
2	IPER1	+	Identifier of first time period of analysis (for example, 1982). All benefits and costs are discounted to the beginning of this time period.
3	DRATE	+	Effective discount rate per period, expressed as a percentage. This is used to determine the present value of all benefits and costs. A nonzero value must be used because site acquisition costs and operation costs are amortized in the analysis. Default value is 1%
4	NDISP	+	Total number of existing and potential disposal sites. This includes disposal sites to which material is moved directly from a dredge site and disposal sites to which material is rehandled from other disposal sites. See note on next page.
5	NDREG	+	Total number of dredge sites. See note on next page.
6	NTRAN	+	Total number of possible dredged-material transportation methods. This includes dredging plants (such as hopper dredges) and rehandling transportation types (such as dump trucks). See note on next page.
7	IPRNT	0	Transportation link input report, disposal site input report, and dredge site input report are printed in addition to list of input.
		1	Transportation link input report, disposal site input report, and dredge site input report are omitted.

J1 CARD (Continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
8	ITMAX	+	Maximum number of iterations allowed for capacity-expansion problem solution. Ignored if system capacity expansion is not to be considered. Default value is 25.
9	NPERAM	+	Number of periods required for amortization of site acquisition or lease costs. Must not exceed NPER.
10	NPREST	+	The restart capability of the program is to be used. A file is prepared for analysis of NPREST periods following the last period of analysis performed in this execution of D2M2. This file is a new input file for the same disposal system. The initial conditions specified in this new file are final conditions determined from the current analysis. The file is identified as TAPE11. The program user must issue appropriate job control commands to re-execute D2M2 with this input file.
		0	File for restart execution of program is not prepared.

NOTE: The available computer memory is allocated automatically by this program based on the requirements for storage of disposal site, dredge site, and transportation data. Thus maximum values for NDISP, NDREG, and NTRAN are not set explicitly. Instead the following restrictions apply for the distributed Harris version of the program:

a. (NTRAN*34) + (NDISP*78) + (NDREG*18) + (NDREG*NPER) + ((NPER+1)*12) + (NDREG*7*MXLNKS) + (NPER+3)*100 must not exceed 40000. MXLNKS is the maximum number of disposal sites to which any one of the dredge sites may transport material (maximum of all values of NTLINK (DL.3)).

b. (((NDISP*2) + NDREG)*NPER) + 2 must not exceed 5000.

c. ((NDISP*(2+N)) + NDREG)*NPER must not exceed 10000. N is the maximum number of transportation links that originate and terminate at any disposal site, including links for reuse and for transfer.

TRANSPORTATION DESCRIPTION

Data on the required TI, TD, and TC cards describe each possible method for moving dredged material within the system, including shipment from sources to disposal sites and shipment between disposal sites in the case of rehandling. NTRAN (J1.6) sets of TI, TD, and TC cards are required.

TI CARD - TRANSPORTATION IDENTIFICATION

The transportation type identification and description are provided on this required card.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	TI	Card identification.
1	ITID	AN	Right-justified 6-character transportation type identifier. This identifier is used later to define system linkages.
2-7	ITNAME	AN	Transportation type description.

TD CARD - DISTANCES FOR TRANSPORTATION-COST FUNCTION

The unit cost of moving material within the disposal system is represented in D2M2 as a function of distance. The values on the required TD card are the distances of the distance vs. unit cost function. The values must be specified in increasing order or execution will terminate. A maximum of 10 values may be provided. Linear interpolation without extrapolation is used, so the values should be selected accordingly. Any desired units of distance may be used (miles, feet, kilometers, meters), however, the units of distances specified on the TD card and the units of all other distances specified must be consistent.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	TD	Card identification.
1	TDIST(1)	+	First distance value. This value must be less than the minimum required transportation linkage distance.
2	TDIST(2)	+	Second distance value.
3-10	TDIST(3)- TDIST(10)	+	Repeat as above for values 3-10 If less than 10 values are specified, the fields remaining after the last value must be blank. The last value specified is the maximum value and must exceed the length of any transportation link in the system.

TC CARD - COSTS FOR TRANSPORTATION-COST FUNCTION

The values specified with the required TC card are the unit costs (cost per unit volume shipped) corresponding to the distances specified in the corresponding fields of the TD card. Any desired units of cost and volume may be used, but all costs and volumes must be specified with consistent units of measurement.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	TC	Card identification.
1	TCOST(1)	+	First unit cost value. This value is the unit cost associated with TDIST(1) (TD.1).
2	TCOST(2)	+	Second unit cost value. This value is associated with TDIST(2) (TD.2).
3-10	TCOST(3)-TCOST(10)	+	Unit cost values corresponding to TDIST(3), TDIST(4),....TDIST(10).

DISPOSAL-SITE DESCRIPTION CARDS

Data on these cards describe each material disposal site in turn. NDISP (J1.4) sets of SI, SL, SX, SS, SE, and SA cards are required. An SR card is required for each disposal site from which material can be rehandled, as identified by a nonzero value for NREHND (SX.9).

SI CARD - DISPOSAL-SITE IDENTIFICATION

The dredged-material disposal site identification and description are provided on this required card.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	SI	Card identification.
1	IDISP	AN	6-character disposal-site identifier.
2-7	IDNAME	AN	Disposal-site description.

SL CARD - DISPOSAL-SITE LOCATION

The values on the required SL card specify the disposal-site location, the transportation type used to move material from the river to the site, site storage data, and fixed operation, maintenance, and replacement (OMR) costs.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	SL	Card identification.
1	SRVDST	+	River distance to location associated with disposal site (see Fig. 2). Any origin for measurement may be used, but all river distances must be specified relative to the same origin.
2	SOFFMN	+	Distance from river to disposal site (see Fig. 2).
3	IDTRAN	AN	Right-justified 6-character identification of the transportation facility used to move material from the river to the disposal site. This value must correspond exactly to one of the transportation-type identifiers on TI cards. If this field is blank, IDTRAN is assumed to be the same as the transportation type used on the river (specified on DT cards), and SOFFMN is added to the river distance for unit cost determination. Otherwise the unit cost is the sum of on-river and off-river unit costs.
4	STOR1	+	Volume of material stored in disposal site at beginning of IPER1 (J1.2). Must not exceed capacity of disposal site.
5	WDRAT	+	Average ratio of volume of "wet" material deposited in site to volume of material after drying. This drying is accomplished within one time step.
6	ADDMAX	+	Maximum allowable addition of unconsolidated material to disposal site per period (volume per period).
		-	The absolute value of ADDMAX is the maximum elevation increase due to addition of unconsolidated material per time step. Linear interpolation of the elevation-volume relationship is used to convert this elevation change to volume change for the network.
		0	The maximum allowable volume addition per time step equals site capacity.

SL CARD (continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
7	STRCST	+	Cost per unit volume of wet material added to disposal site. This cost includes operation costs that are a function of the volume deposited in the site, including mitigation costs.
8	OMRCST	+	Fixed annual operation, maintenance, and replacement cost for disposal site. This cost is incurred at the end of each period a site is available, regardless of the volume of material stored in the site.
9	ISTPRT	0	Disposal-site operation report includes tabulation of material added to and material removed from site each period, disposal-site status each period, and total volumes added and removed during period of analysis.
		-	Disposal-site operation report includes tabulation of material added and removed and disposal-site status for period that site initially fills, tabulation of final site status, and tabulation of total volumes added and removed.
		+	Disposal-site operation report includes tabulation of material added and removed and disposal-site status for period that site initially fills and for period ISTPRT, tabulation of final site status, and tabulation of total volumes added and removed.

SX CARD - EXPANSION SPECIFICATION

The values on the required SX card include site-acquisition data, lease data, reuse data, and rehandling data.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	SX	Card identification.
1	IEXP	0	This disposal site is added to system at beginning of period IPERA (SX.3) and is available until lease expires at end of period LLEASE (SX.4). The site is then deleted from the system
		1	This disposal site is added to system at beginning of period IPERA (SX.3). The lease is renegotiated at end of period LLEASE (SX.4) at a cost of RENCST (SX.5), and the site is available throughout the analysis.
		2	This disposal site is added to system at beginning of period IPERA (SX.2). Lease renegotiation at end of period LLEASE at a cost of RENCST is considered as a capacity expansion option. This option cannot be exercised with the program "restart" capability.
		3	Acquisition of this site is a capacity expansion option. The site may be acquired between IPERA and IPERG (SX.3), inclusive, at a cost of ACQCST (SX.10) and will then be available for the remainder of this of analysis. This option cannot be exercised with the program "restart" capability.
2	IPUSE	+	Columns 9-10 contain a 2-digit number defining the number of periods a site is available prior to "resting". The site is added to the system in IPERA (SX.2) as specified by the user (or as selected by the capacity expansion algorithm). The site is then alternately included for IPUSE periods and omitted for IPREST periods.
		0	Site is not rested.
	IPREST	+	Columns 11-12 contain a 2-digit number defining the number of periods a site is rested in the alternating using-resting cycles.
		0	Site is not rested.

SX CARD (Continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
	IPERA	+	Columns 13-16 contain a 4-digit number. If IEXP = 0, 1, or 2, this is the period of site acquisition. If IEXP = 3, site acquisition is a capacity expansion option, and acquisition will be considered only during or after IPERA. If omitted, IPERA is set equal to IPER1 (J1.2).
3	IPERG	+	Last period within which capacity expansion by acquisition of this site will be considered. This value must not exceed IPER1 + NPER - NPERAM to insure that the site acquisition cost is fully amortized within the period of analysis. Ignored if IEXP is not equal 3.
4	LLEASE	+	Period of lease termination. If IEXP = 0, the disposal site is deleted from the system at the end of this period. If IEXP = 1, the lease renegotiation cost is incurred at the end of this period, and the site remains in the system throughout the analysis. If IEXP = 3, LLEASE is ignored. Omit if site is available throughout analysis.
		0	Lease does not terminate. Disposal site remains in system throughout analysis (including subsequent "restart" analysis, if that option is used).
5	RENCST	+	Lease renegotiation cost. Required if IEXP = 1 or 2. This cost is incurred at the beginning of period LLEASE+1 if the lease is renegotiated.
6	IPERR	+	First period reuse is possible. This applies only to sites with known acquisition period (IEXP = 0,1) and with positive value for REMAX (SX.7). If reuse from a potential site (identified by IEXP = 3) is possible, it is assumed to begin when site is acquired. In that case, this field is ignored.
7	REMAX	+	Maximum volume that may be removed per period for reuse. REMAX must not exceed site capacity. Omit if no reuse from this disposal site.
8	REBEN	+	Unit benefit of reuse of material from this site.
9	NREHND	0	Material from this site cannot be transferred to other sites within the system.

SX CARD (Continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
		+	Number of sites to which material from this site may be transferred. Maximum value is 2. Data describing the transportation links to these sites are provided on the SR card.
10	ACQCST	+	Total site acquisition cost. This cost may include cost of facilities, of real estate, and of mitigation of adverse environmental or cultural impacts.

SR CARD - TRANSFER DESCRIPTION

The data on this optional card describe the potential facilities for transferring material from the disposal site identified on the SI card. The SR card is required if NREHND (SX.9) is positive.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	SR	Card identification.
1	IRESIT(1)	AN	Right-justified 6-character identification of the first disposal site to which material may be transferred. This site must be described also by data on SI, SL, SX, SR, SS, SE, and SA cards.
2	IREPER(1)	+	First period that transferring from site IDISP(SI.1) to site IRESIT (SR.1) is possible. This applies only to sites with known acquisition period. Otherwise transfer is assumed to begin when both sites IDISP and IRESIT have been acquired.
3	REDIST(1)	+	Distance to site IRESIT.
4	IRETYP(1)	AN	Right-justified 6-character identification of the transportation method for transferring material. This value must correspond to one of the transportation types specified previously on TI cards.
5	REHMAX(1)	+	Maximum volume per period that may be transferred to site IRESIT. If no value is specified, maximum site capacity is used.
6	IRESIT(2)	AN	Same as IRESIT(1), but for second transfer site, if one is available.
7	IREPER(2)	+	Same as IREPER(1), but for second transfer site, if one is available.
8	REDIST(2)	+	Same as REDIST(1), but for second transfer site, if one is available.
9	IRETYP(2)	AN	Same as IRETYP(1), but for second transfer site, if one is available.
10	REHMAX(2)	+	Same as REHMAX(1), but for second transfer site, if one is available.

SS CARD - DISPOSAL-SITE CAPACITY

The data on the required SS, SE, and SA cards describe the capacity, surface elevation, surface area relationship of the disposal site. Any consistent system of measurement may be used. The values are specified such that CAPCTY(1) is the capacity corresponding to ELEV(1), which corresponds to AREA(1). The storage values specified must increase or execution will terminate. The same number of values must be specified on each of the cards. A maximum of 9 values may be provided. Linear interpolation without extrapolation is used, so the values specified should be selected accordingly. The last nonzero value of the SS card is assumed to be the maximum allowable volume of material deposited in the site.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	SS	Card identification.
1			Not used.
2	CAPCTY(1)	+	First storage value
3-10	CAPCTY(2)-CAPCTY(9)	+	Storage values 2-9.

SE CARD - DISPOSAL-SITE ELEVATION

The required SE card identifies the elevations corresponding to the capacity values of the SS card.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	SE	Card identification.
1			Not used.
2	ELEV(1)	+	First elevation value. This is the elevation that corresponds to CAPCTY(1).
3-10	ELEV(2)-ELEV(9)	+	Elevation values 2-9, corresponding to storage values 2-9 on SS card.

SA CARD - DISPOSAL-SITE AREA

The surface area values of the capacity-elevation-area relationship are specified on this required card.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	SA	Card identification.
1			Not used.
2	AREA(1)	+	First surface area value. This is the surface area that corresponds to CAPCTY(1).
3-10	AREA(2)-AREA(9)	+	Area values 2-9, corresponding to storage values 2-9 on SS card.

DREDGE-SITE DESCRIPTION CARDS

Data on these required cards describe each dredge site in turn. NDREG (J1.5) sets of DI, DL, DT, and DV cards must be included. Within each set, one DT card is included for each possible linkage of the dredge site with any disposal site.

DI CARD - DREDGE-SITE IDENTIFICATION

The dredge-site identification and description are specified on this required card.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	DI	Card identification.
1	IDREG	AN	Right-justified 6-character dredge-site identifier.
2-7	IDRNAM	AN	Dredge site description.

DL CARD - DREDGE-SITE LOCATION

The data on the required DL card specify the dredged-material source location, the number of links of the source with disposal sites, and the multiplier that may be used to scale all the specified material volumes for this source.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	DL	Card identification.
1	DRVDST	+	River distance to dredged-material source location. The origin of measurement must be constant and the same used for specification of disposal-site location.
2	DOFFMN	+	Distance from river to dredge site. If dredge site is on a tributary, this is the distance from the point of intersection of the tributary and the main channel.
3	NTLINK	+	Number of possible links of this dredged material source with existing or potential disposal sites. These links are defined by DT cards that follow.
4	VMULT	+	Material-volume multiplier. All material volumes specified on DV cards for this dredge site are multiplied by VMULT prior to analysis.
		0	VMULT is assumed equal to 1.0.

DT CARD - DREDGE SITE TO DISPOSAL SITE TRANSPORTATION DESCRIPTION

One DT card is required to describe each possible link of this dredged-material source to existing or potential disposal sites. A total of NTLINK (DL.3) cards are required.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	DT	Card identification.
1	LDID	AN	Right-justified 6-character identifier of site to which material may be transported for disposal. This identifier must match exactly one previously specified on SI cards.
2	LMTYP	AN	Right-justified 6-character identifier of method used for transportation of material on river. This identifier must match exactly one previously specified on TI cards.
3	LOFTYP	AN	Right-justified 6-character identifier of method used to transport dredged material from source to river. This identifier must match exactly one previously specified on TI cards. Omit if DOFFMN (DL.2) is zero. If this field is blank, LOFTYP is assumed to be the same as LMTYP (DT.2). In that case, DOFFMN (DL.2) is added to the river distance for unit cost determination.
4	VLMAX	+	Maximum allowable volume per period that may be transported via this transportation link. If no value is specified, the entire volume removed from this site each period is used as the limit.

DV CARD - DREDGED-MATERIAL VOLUMES

The volume to be transported from the dredge site each period, before drying, is specified with the required DV card. Ten values are specified per card. NPER (J1.1) values must be specified, unless a constant volume is to be used. In that case the value specified for the first period is used in all subsequent periods. This is controlled by the presence of -1 in field 3. If VMULT (DL.4) is nonzero, all volumes specified or implied are multiplied by VMULT.

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	DV	Card identification.
1			Not used.
2	VOLMAT(1)	+	Volume of "wet" material to be transported from this dredge site, period IPER1.
3	VOLMAT(2)	+	Volume of "wet" material to be disposed, period IPER1+1.
		-1	The volume of material for period IPER1+1 and for all subsequent periods is VOLMAT(1)*VMULT. No additional values are required on this card and additional DV cards for this site are not required.
4	VOLMAT(3)	+	Volume of "wet" material to be disposed, period IPER1+2. Omit this value and subsequent values if VOLMAT(2) = -1.
5-NPER	VOLMAT(4)-VOLMAT (NPER)	+	Volume of "wet" material to be disposed in remaining periods. If NPER exceeds 9, use addition cards as needed, with 9 values per card, beginning with Field 2 of each card.

USER-SPECIFIED SOLUTION

Data on these optional cards force transportation of a specified volume of dredged-material from a specified source to a specified disposal site regardless of the cost. If multiple transportation linkages exist, the transportation type must also be specified. The user must realize that fixing a portion of the solution in this manner may yield a network-flow programming problem to which no solution exists, especially in the case of capacity expansion sites. Furthermore, the user must define a feasible solution; the linkage must exist, the volume to be transported must not exceed the capacity of the disposal site, and transporting and disposing the material must not cause overfilling of the disposal site in a single period.

FS CARD - FIXED SOLUTION SPECIFICATION

FIELD	VARIABLE	VALUE	DESCRIPTION
0	KODE	FS	Card identification.
1	JDREG	AN	Right-justified 6-character identifier of the dredged-material source. This value must correspond exactly to one of the sources identified on DI cards.
2	JDISP	AN	Right-justified 6-character identifier of the disposal site to which material is to be transported. This value must correspond exactly to one of the disposal sites identified on SI cards.
3	JPR	+	Period in which specified value is to be transported. Both IDREG and IDISP must be available in period IPER or execution will terminate.
4	VOL	+	Volume to be transported. Must not exceed volume specified on DV card for source IDREG, period IPER.
5	JTRTYP	AN	Right-justified 6-character identifier of the transportation method used, if more than one type of linkage exists. This value must correspond exactly to one of the transportation types identified on DT cards.

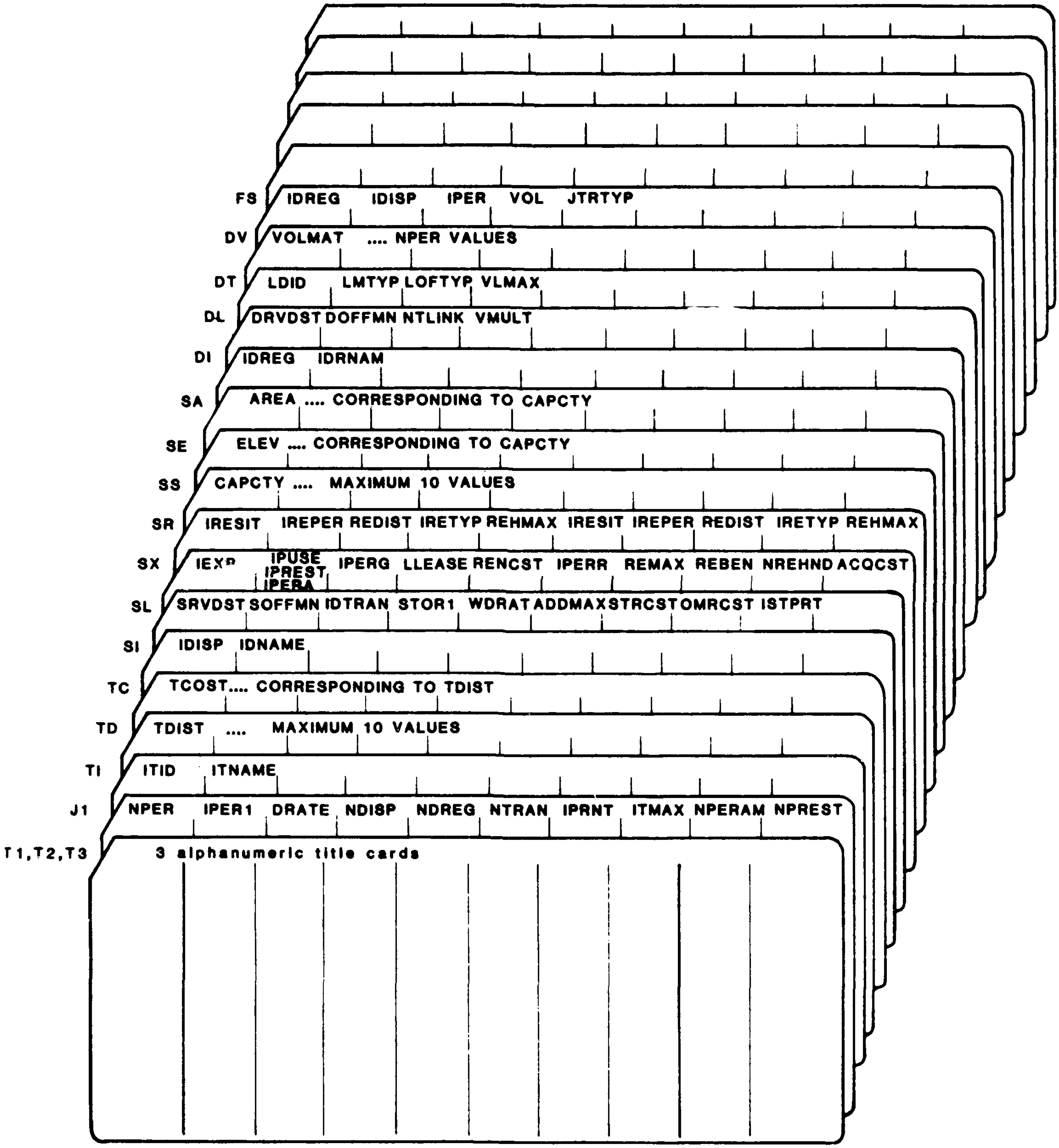

FIG. 7. - Summary of Program D2M2 Input